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Rudich, William Lawrence (M.S., Civil Engineering)

A Study of Central Energy Monitoring and Control (CEMC) Systems

Report directed by Assistant Professor Clift M. Epps

The Central Energy Monitoring and Control (CEMC) systems began in the 1950s as an attempt to reduce rising labor costs in building management. The ensuing development of the computer and the mini-computer which created more sophisticated systems and the start of the "energy crisis" started their application for energy reduction and optimization in facilities.

This report explains the components of a computer-based CEMC system, its functions and its capabilities. Other types of systems are briefly described for comparison. The terminology peculiar to CEMC systems is defined and some of the systems available today are described. The results of questionnaires sent to present users of these systems are discussed.

The problem with the specification and procurement of CEMC systems is presented. The source of the problem and some solutions proposed by others are given.

The use of CEMC systems on College Campuses is discussed. The history of the proposed system installation on the University of Colorado Boulder campus is reviewed and updated.

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A STUDY OF CENTRAL ENERGY MONITORING AND CONTROL (CEMC) SYSTEMS

by

William Lawrence Rudich

B.S.C.E., Union College, 1973

A report submitted to the Faculty of the Department
of Civil and Environmental Engineering
of the University of Colorado in partial
fulfillment of the requirements for the degree of
Master of Science, Civil Engineering
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This Report for the Master of Science,

Civil Engineering Degree by

William Lawrence Rudich

has been approved for the

Department of

Civil and Environmental Engineering

by

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This abstract is approved as to form and content.

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CHAPTER I

INTRODUCTION

A. Purpose of Report

The Central Energy Monitoring and Control (CEMC) system concept began in the 1950s as a means to reduce rising labor costs. The development of computers and sophisticated mini-computers and the start of the "energy crisis" in the 1970s initiated their application for reducing energy consumption [30].[1]

This Chapter discusses the general concept of central energy monitoring and control and the history of CEMC systems, with emphasis placed on computerized CEMC systems. Chapter II discusses these systems in general terms. The components and terminology peculiar to these devices are defined and described. The capabilities and the advantages that they offer are mentioned.

Chapter III describes the hardware and software components and capabilities of some of the CEMC systems available today. The information is provided by the manufacturers. Chapter IV explores the experiences of some present users of CEMC systems. The projected and actual savings are compared. The problems encountered and proposed solutions are related.

[1]All bracketed numbers refer to the list of references at the end of the report.

Chapter V discusses the current problem of procuring CEMC systems and relates some possible solutions proposed by various people. Chapter VI reviews and discusses the proposed installation of a CEMC system on the University of Colorado at Boulder campus. CEMC system applications at other Universities are studied as a comparison for the possible cost savings and benefits.

The final chapter summarizes this report and discusses future developments that will change CEMC systems and their uses.

B. The Central Energy Monitoring and Control Concept

The intent of a CEMC system is to allow equipment at one or two locations to monitor and control an entire facility's energy use, life safety, and security needs. A single operator can implement a predetermined energy conservation or security program. Decisions concerning the operation of the facility are made with the knowledge of current data including temperatures, pressures, fan and motor running status, etc. There is closer supervision of the facility, permitting quicker responses to problems when they occur.

The system's central console receives and displays building data. The operator can check the temperature, humidity, fan and motor running status, etc., in various locations without personally visiting the site.

The monitoring and control can be performed in many ways. A central console can be equipped with indictor lights or gauges to show the current facility data. This console exercises little control if any over the connected devices. A time clock does not monitor, but it can switch equipment and lights on and off based on the time of day. A multiplexing system utilizes a single channel to monitor and control several points at the same time. Computerized systems which are the subject of this study can monitor the points and collect the data for use in calculations which can determine the mode of operation that will consume the least amount of energy, or indicate the security status of the building. The computer is able to react to a variety of situations and implement pre-programmed strategies. The programming can be revised to meet changing facility needs.

C. The History of CEMC Systems

The first attempts at central energy monitoring and control began in the 1950s. One of the first applications was in the White House. A central panel controlled 106 thermostats, 112 valves and 97 relays and switches. The large central panel had gauges and dials which were connected to the sensors and controllers by individual wires or pneumatic lines. A system of this type could not be easily used to control more than one building. The individual connections to each point were cumbersome and

bulky. The central panel was able to do little more than start and stop the equipment.

In the mid-1950s, the use of time-sharing graphic displays reduced the size of the control consoles. Hard-wired logic circuits in the Central Processing Unit (CPU) could store the values received from the remote points. These circuits could digitally display the data so that the dials and gauges were replaced. These same circuits were installed at the remote locations to store data so that the transmission lines could also be shared. These more advanced systems were primarily used to monitor temperatures and pressures and to report abnormal conditions. Their control functions were limited to the start up and shut down of equipment, based on a time of day schedule and the adjustment of the set points.

The 1960s introduced multiplexed data transmission systems which used a field panel to convert the signals to a digital form for transmission to the CPU. A two or four-wire cable from the CPU to the field panel replaced the individual wires from each sensor to the CPU. This channel was controlled by the field panel so that the data was transmitted over this common channel.

Telemetry techniques similar to those used on space probes and long-distance telephone lines helped to increase the distance over which sensors could communicate

with the central control panel. Baptist Memorial Hospital in Memphis used an early telemetry system. The sensors were one mile from the control panel. In the late 1960s, the U.S. Postal Service monitored buildings in Mobile, Alabama, Wilkes Barre, Pennsylvania, and Greensboro, North Carolina from a central panel in Dayton, Ohio. This system used long-distance telephone lines to send the data.

The application of the Cathode Ray Tube (CRT) enabled many values to be displayed on a single device. The sole drawback of this console was that it used hardwired logic circuits which only permitted the display of previously identified values. If an additional point had to be connected to the system, the entire console had to be rewired.

The development of medium-scale integration (MSI) technology in the 1960s permitted a maximum of twelve functions to be placed on a single computer chip. In the 1970s, the aerospace industry development of large-scale integration (LSI) technology increased the number of functions to one hundred per chip. These more capable chips replaced transistors in computers and decreased their size and cost. In 1965, the first mini-computer was marketed. In 1970 the first computer-based CEMC system was marketed. The computer's software gave the console more flexibility to adapt to changing needs and conditions. The console only needed to be reprogrammed

instead of rewired. Software programs in high-level languages such as FORTRAN IV enhanced the data management capabilities and decreased the requirement for skilled computer programmers to make system changes [11].

These developments and the new emphasis on energy conservation which resulted from the 1973 oil embargo started the widespread use of computer-based CEMC systems for facility energy management. In 1973 buildings accounted for 20% of the total energy use in the United States [15]. In an effort to decrease this figure, CEMC systems and other methods such as more energy-efficient designs were implemented.

Small-scale computers and mini-computers reduced the cost of a computer from $250,000 to a range between $2,000 and $25,000. The mini-computers operated at a slower speed and had decreased capabilities which were adequate for the CEMC systems which had to interface with slow acting building systems.

The mini-computer system uses standard computer, transmission and sensor components and standard software routines. The mini-computer can perform calculations on the data it collects and initiate actions based on the results. The programming is usually written so that the building owner can moidfy the control algorithms. The original manufacturer does not have to be retained for changes to and expansion of the system. This development

helped to overcome one of the problems which had discouraged the use of CEMC systems.

In 1974, it was estimated that 200 million dollars was spent on CEMC systems. At that time it was projected that this total spending would rise to 775 million dollars in 1985. Part of this increase was attributed to an increase in the retrofit applications which became economically feasible because of the reduced cost of the mini-computer [5].

During the 30 years since the introduction of CEMC systems, their function has evolved from that of a simple monitoring system to that of an overall facilities controller. This development is discussed in the remainder of this report.

CHAPTER II

CENTER ENERGY MONITORING AND CONTROL SYSTEMS

A. Introduction

The components and functions of a CEMC system are presented in this chapter. A CEMC system is composed of hardware and software. The hardware is the mechanical and electrical equipment. The software is the programs and algorithms that operate the equipment and give it instructions, so that desired control functions are performed. Some of the functions performed by CEMC systems are described in this chapter. The types of systems are discussed after the description of the hardware and software.

B. Terminology

A problem associated with CEMC systems is the lack of a commonly-defined terminology. To help understand the technology and features described in this chapter, the necessary terms are defined in Appendix B.

C. Hardware

The hardware parts of a CEMC system consist of the Central Processing Unit (CPU), the memory, the input/ output devices and the input/output interfacing devices. They are connected by a communication link which uses

multiplexing techniques to share a common channel. Figure I shows the configuration of these pieces for a basic computer-based CEMC system.

Sensors or controllers which monitor and/or control points are wired into interface devices (ID), which may also be called field panels. The sensors and controllers may be located at a considerable distance from the central control point. The panels, which may have more than one sensor or controller connected to them, convert analog signals into a digital form for transmission to the central monitoring station. A digital form consists of high-speed spurts of on/off pulses that create "words" that are the commands and point designations or addresses for the system.

As the messages are sent, they are checked for accuracy by retransmitting them a second time to see if the signals are identical. If they are not, a second set of transmissions is sent. If this set does not match, the operator is alerted by an alarm that the system is malfunctioning.

The ID monitors the sensors by a multiplexing technique. Multiplexing is a process which sends two or more signals through the same wires at the same time. The connected points are addressed in sequence and the signals are sent or received. A timing signal is used to check

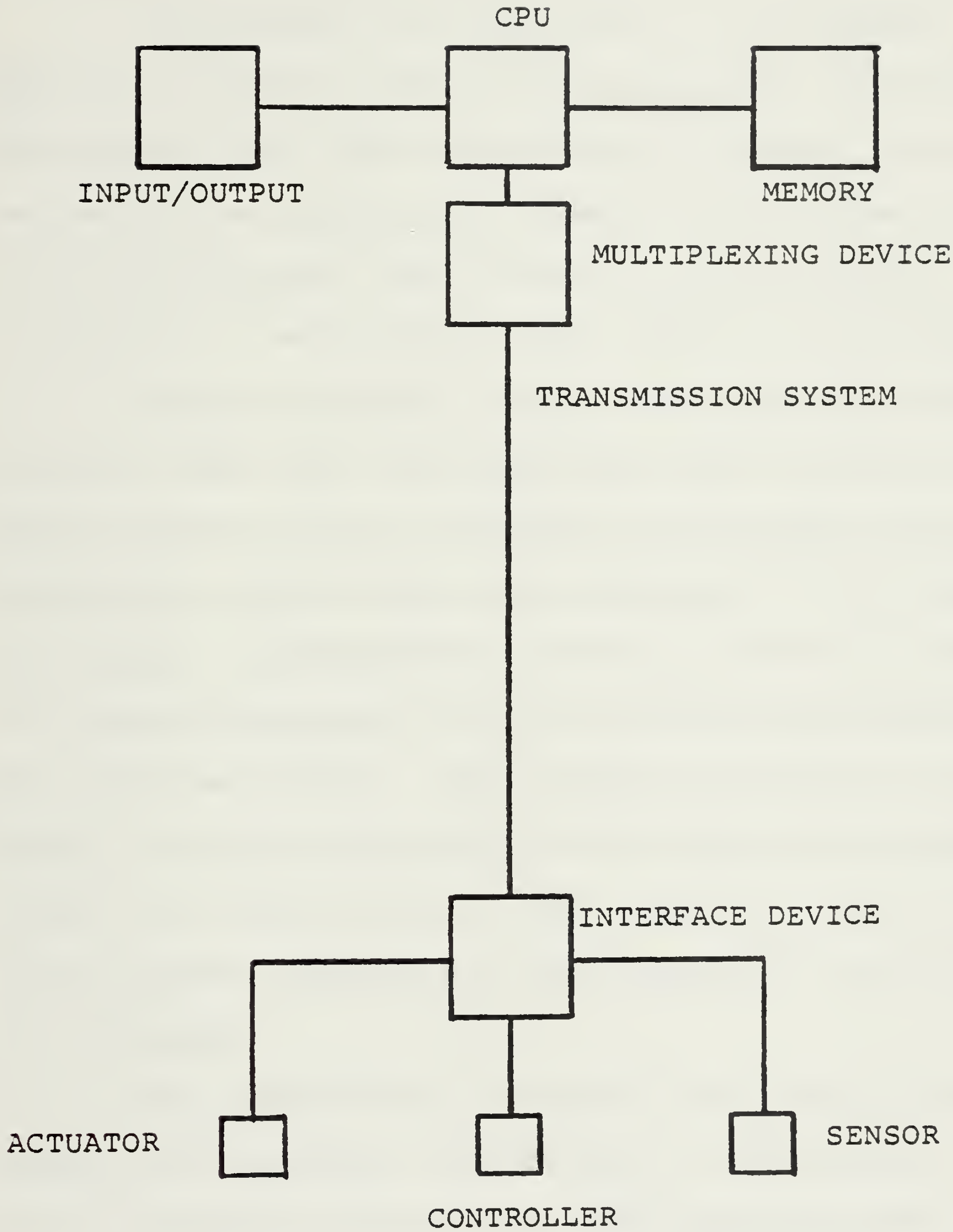

Figure 1. CEMC System Block Diagram.

and activate each circuit on a frequent basis. Alarm signals can override and take precedence over routine messages so that there is no delay in the notification of the operator.

The messages are translated by the computer. The data can be stored and/or displayed by the output device. The operator can make adjustments by entering the point address and an appropriate command. This signal is sent to the field panel which directs it to the point. The controller is activated and the command is executed.

Whenever possible sensors and controllers are electronic so that they are compatible with the control system. Analog sensors (such as penumatic thermostats) must be used with signal conditioners and transducers to tie them into the system. A transducer converts an external signal such as pneumatic pressure to an electrical form suitable for the interface device. These sensors measure the temperatures, pressures, the position of mechanical devices and relays and switch status. The controllers are actuators which execute commands and can be motors, valves, switches, or contactors.

The conversion of a signal from analog to digital form is called signal conditioning. It is usually done in the interace device (ID). New micro-electronic technology has created "smart sensors" which can do this task. These devices will be discussed later in this report. The converter which is a transducer changes the analog

data into a binary form which is a group of bits. One bit is the smallest unit of information that a computer can deal with. Each of the bits has a different significance. The number of bits that will be worked with will determine how accurate the conversion must be. Walton N. Hershfield gives the following example to illustrate this point:

> If the converter's resolution is 8 bits, a temperature range is divided into 2, 8, or 256 sections which can give an accuracy up to 6. A change in the number of bits will give a different number of sections and significant figures. [13]

The converter does not compensate for measurement errors. Its resolution only preserves the data that it receives. Digital to analog conversion which is the reverse of the analog to digital translating, is used to adjust set points and control dampers, etc.

The interface device (ID) is the link between the sensors and controllers and the central control point. The number of devices connected to the ID will depend on the size of the panel which can be varied as required. The ID contains the circuitry required to receive and send data over the transmission link, and to transmit commands to the controller. The ID usually contains the analog to digital converter and the signal conditioning transducer.

The first of the ID's basic functions is to contain the addresses of its attached sensors. It adds the address code to all data sent to the central control point. Messages

from the central control point are routed through the ID to the specified point.

The ID also acts as a buffer which is a device used to store data collected by the previously described multiplexing techniques from the slower acting sensors until it can be sent at a rapid rate of transmission that is compatible with the high speed of the computer. The ID contains an internal clock which insures the performance of certain functions on a regular schedule. An example is the periodic scanning of all connected sensors and the transmission or storage of the data collected.

The data transmission system links the ID and the CPU. The system may be a loop wired through all of the ID units before returning to the CPU. Another configuration is to have a direct connection out and back from each ID to the CPU. The communication link uses multiplexing techniques. Data is transmitted on a time-sharing basis with alarm signals having the priority as previously described.

The methods used to send the data signals vary with the size of the system and the distances to be covered. Many of the systems use a combination of the methods to be described. The most important consideration is the rate of data transmission. It is called the baud rate and is measured in bits per second. The data transmission rate must be fast enough so that it does not delay

the high-speed computer which is the governing piece of equipment.

Coaxial cable is considered the most efficient means of signal transmission from remote facilities to the central control point. It can accept multiplexed signals and there is virtually no limit to the number of facilities or points that can be added. It has a high data transmission rate which is complemented by a low error rate. The error rate is the expected ratio of undetected errors to detected errors that is computed by statistical methods for each mode. Its only drawback is the high initial cost which can be considerable if the facilities are spread over a large area.

Twisted shielded wire pairs have a transmission performance similar to coaxial cable. Its expandability, maintainability and multiplexing capabilities are the same as for coaxial cable. The rate of data transmission is slower and varies with the type of twisted pair shield used.

In certain situations, VHF-FM radio signals are being used to transmit control and sensor data signals. There is an initial problem of obtaining an operating frequency. The signals are subject to interference from airplanes and other radio transmitters which reduces the reliability. For this reason it is not widely used on large systems. The VHF-FM radio link has a high initial cost for transmitters and receivers. It is not easily expanded because

each new separately controlled point requires a new separate frequency which as noted above can be difficult to obtain.

Over long distances, microwave transmission can be used. It is reliable and easily expandable. There is a high initial cost for the transmitters and receivers that must go into each building. The equipment is very complicated and qualified personnel must be available for maintenance and repairs.

Telephone lines are the most commonly used form of communication between buildings. They require a low initial capital investment. The specification for this mode must clearly state the quality of transmission required since there are many different quality lines available. The expandability of the system could be limited by the equipment and telephone pairs available [25].

The main part of a CEMC system is the Central Processing Unit (CPU). It may be a full-sized digital computer, a mini-computer or a mircoprocessor. The full-sized computer is the same machine used in data processing operations. They are complex, sophisticated machines whose capabilities and speed exceed the needs of a CEMC system. They are very expensive and can make a system economically unfeasible unless the computer can be used for other tasks on a time-sharing basis. A mini-computer

is a general use computer that is about as large as a suitcase. Its speed and capabilities are comparable to a full-sized computer. Tape or disc systems can be used to add memory storage. Mini-computers are easily reprogrammed to adjust for changes in operating conditions. Their cost may range from $2,000 to $25,000. A microprocessor is part of a computer designed to operate a supervisory system. The addition of a memory and input/output devices transforms the microprocessor into a mini-computer. The microprocessor is used in computer-type CEMC systems. It can be programmed by using assembly language. Its programmability permits more flexibility as a replacement for hardwired circuits. The mircoprocessor alone cannot perform calculations on the data that the system collects. It cannot compare the data to ideal conditions so that changes for a more efficient operation can be made. It does contain timing circuits and an arithmetic and logic unit. It can interpret instructions, and exercise control over the connected points. Systems with computers as the CPU now use microprocessors as field panels to take the control burden off of the CPU. This concept of distributed processing will be discussed later [11, 12, 22, 27, 28].

The computers have different types of memory. The contents of a volatile memory will be lost if the

power supply is interrupted. A random access memory is volatile. Magnetic core memory, data stored on discs or tapes and read only memories are non-volatile. They do not require a continuous power source. After a power failure, the memory is intact and can contain programming to start up the controlled equipment and resume normal operations.

The operator's console is the link between man and machine. It must interface between a high speed computer and a slower acting human. If the transition is not successful the benefits of computerization will be lost. The most common type in use is the Cathode Ray Tube (CRT). This displays the current values monitored at the remote points. It has a keyboard which is used by the operator to correct the programming, issue commands and request additional data. The normal typewriter keys are augmented by special keys that activate preprogrammed routines such as a printout of the alarm summary.

In large installations where the CEMC system is scanning several different systems such as the HVAC in different buildings, or very large, complex systems in a single structure, a graphics projector is usually provided. It is placed near the console to project slides of the building systems and floor plans. The system will automatically show the slide that corresponds to the points or area that the operator is scanning.

The language on the slide must be simplified so that the operator does not become confused. The slides should be color-coded for easy for easy identification of the systems. The slides should be duplicated in a binder in case the projector fails to operate.

An automatic typewriter or printer is connected to the system to provide a hard copy log of the system operations. It provides a permanent record of the system operations, alarm and maintenance notes and the sensor data if desired. The need for maintenance personnel to write out logs is eliminated. The chance of an error is reduced. In smaller systems without a CRT, the printer is the only output device.

D. Software

The previously described hardware is controlled by the software programs which tells them what to do and how it is to be done. The software performs all the timing, addressing, analysis and interpretation of data and operator commands, and control of the communication links. If the software program is inflexible, complex, and not easily modified, it will not be able to meet the needs of the facility. The performance of the system will be less than expected.

The first part of the software is the operating program. The task scheduling, storage allocation, memory management, input/output operations, error

monitoring and communication between the hardware and software is under its control. The operating system is best contained in the computer to allow the operator to issue commands with a keyboard instead of throwing panel switches. It determines to what degree the operator will have to intervene for the system to operate. Operating systems can be divided into two categories; stand alone and disc-based.

In a stand-alone system, the operating system and application programs are contained in the main computer memory. A disc-based operating system stores a portion of the operating and application programs in peripheral storage on magnetic discs. The disc-based arrangement is better suited for larger systems. It enables the operator to keep both old and revised programs in memory so direct comparisons can be made without any lengthy input routine for the old algorithm. The disc allows rapid access to the memory data so that the system is not delayed.

Another division of operating systems is into batch oriented and real time oriented systems. The batch oriented system does not allow the programmer to develop new routines without taking the system off line. In a real time environment new application programs can be written or modified while the system functions in its real time environment. The operating system is able to divide the tasks between the real time operating mode

and the program development. The continuous operation permitted by the real-time system enables the benefits of the monitoring and control activities to continue.

The programmer is helped in developing the system software by the support programs. When the system is put into operation, they perform the diagnostic tests on the computer and remote hardware to ensure proper operation. The support programs include assembly language programs, high-level language compilers, debugging and batch loading programs. The most important of these are the high-level language compiler and the debugging and batch loading programs for modifying the application programs which are usually written in assembly language.

The application programs monitor the field conditions, annunciate alarm messages, perform calculations on field data to convert it into engineering units for the display, and perform all tasks that help to optimize energy use, and control assigned building functions.

Real time and event initiated application programs are activated by field generated occurrences such as an alarm or elapsed time on the internal clock. Load shedding, alarm tours, alarm and maintenance instructions are examples of events which activate these routines. Periodic application programs are executed on a regular basis. The automatic start up and shut down of equipment, duty cycling, and lighting control are periodic application

programs. Batch application programs are run once during a period at the operator's request. They list data and summarize conditions such as alarms during a certain period.

Software can be written for a system in a single application. This custom tailoring has an expensive initial and modification cost. The new trend is to use modular software which is written to do certain functions such as equipment start up/shut down, data analysis, energy optimization, etc. It will work on any system that is able to feed the data base, consisting of the point locations and their normal values for temperatures, on/off, etc., to the software. It is less expensive and is written in a manner that allows changes to be made quickly and inexpensively. Modular software also allows the hardware to be retained when changes are made [11, 12].

E. Types of Systems

There are many types of CEMC systems available. They vary in their capabilities, hardware and limitations. Thomas Reinarts [23] in his articles on the specification of CEMC systems defined four levels of systems.

The first level is the basic local control. These function to activate and deactivate switches and controls, and have indicators to show if an item is malfunctioning. Time clocks, local alarms and annunciators are put in this category. These systems are used to control one or two

pieces of equipment such as a fan or a simple system such as lighting in a single or small number of buildings.

The next level system is a central processor system. The control is performed from a central location by a preprogrammed controller. The system is hardware-based and care must be taken to avoid a system that is not compatible with other hardware. The processor initiates commands from the central location that are sent to the controllers. This system can perform remote start/stop of equipment based on time, temperature variation, etc. It is able to monitor systems for running status and parameter out of bounds alarms. Load shedding and cycling are within this system's capabilities.

The third level system adds a computer to the central processor system. The processor can initiate the commands after evaluating several parameters instead of one. For example, it can direct the shut down of an air conditioning if the temperature fails below a preset point instead of using the time of day for this decision. The processor is able to react to different situations by using the computer's programming. This programming can be modified to adapt to new requirements.

The computer can monitor and control several microprocessors. The microprocessors which can control the equipment can be placed in each separate building. The microprocessor can collect the data and initiate

certain actions without signalling the CPU. This concept is called distributed processing. It is very efficient since there is localized control in the same area as the sensor. The central computer is not burdened with the control processes, and is able to be used for the computations necessary to optimize the energy use. The only function that the CPU must perform is to scan the microprocessors for alarm signals.

The microprocessor system can perform the functions of the two other systems. It is able to monitor life safety systems such as the fire alarms.

The most sophisticated system consists of a bulk memory added to the microprocessors and computer. The memory permits the system to store data, perform more calculations, and to evaluate more conditions and parameters prior to initiating action.

The additional functions are: 1. Optimization; which uses the computer to calculate when certain equipment is used to its fullest potential. 2. Security. 3. Plotting of curves with the data collected for comparison with ideal projections or past performance. 4. Maintenance programming where equipment operation is monitored and checked against the ideal performance curves to determine when maintenance or repairs are required. The system can keep track of the running time for the different pieces of machinery and indicate when scheduled maintenance is due to be done [23].

The second level system is a conventional centralized controller. The third and fourth level systems are computer based. All of the systems perform the basic monitoring and remote control functions. However, the computer based system can accommodate printers, CRT consoles, projectors and input keyboards. The computer permits the use of English language input/output, the formating of data and calculation of the optimum energy use. Its programming gives it the flexibility needed to adapt to changes.

These full-scale computer systems such as the level four machines can be subdivided into Power Management and Building Automation Systems. The Power Management System is designed to reduce electrical costs by containing the power demand within a preset limit. The Building Automated System which is called the CEMC system in this report lowers total energy consumption by managing its use by all building systems. The primary purpose of this report is to discuss the Building Automation Systems. A brief discussion of Power Management systems is included to show what they are designed to do.

As previously stated, a Power Management System reduces the electrical demand and electrical consumption charges. The demand is defined as the average power measured in kilowatts (KW), consumed during a specified time. It is computed from the largest kilowatt hour (KWH)

consumption for the period specified. The electrical energy charge is for the energy consumed during the entire billing period. It is measured in KWH.

The demand charge is used by the utility company to help pay for the capital investment cost of the standby equipment needed to meet the peak demands. Once it is established by the largest consumption, the demand may not be reduced even if it sharply decreases. The use of "ratchet clauses" in the utility rate structure by the power companies enables them to bill customers for a certain percentage, such as the 75% used by Public Service Company of Colorado, of the highest demand during the previous eleven months. The demand charge is a considerable portion of a commercial utility bill. The establishment of a new higher demand can cost a firm additional funds for a period far beyond that in which the consumption peaked.

The electrical energy charge covers the cost of producing the power and running the utility company. The fuel, personnel salaries, the generation and transmission, billings and other paperwork costs are covered in the charge per KWH. The reduction of the electricity use to contain the demand will reduce this energy cost.

To accomplish demand limiting, the electrical loads are divided into essential (non-sheddable) and sheddable loads. Sheddable loads include corridor and garage lights,

certain fans and pumps, heaters and air conditioning chillers, and other devices that can be switched off without danger or great inconvenience. Essential loads are those such as elevators, computers, and other equipment that will cause a hazard or be damaged by an interruption of the power.

The system monitors the power use and will alert the operator if the start up of additional equipment will cause the demand to be exceeded. The operator or in many cases the system decides if the start of the piece of equipment can be delayed or if lower priority loads should be shed. Some of the loads can be shifted into less active periods so that the demand will be more constant.

Power Management systems compute the maximum demand by one of three methods. The methods insure that a preset demand limit is not exceeded by the consumption during a certain time period.

The ideal rate method: The energy consumed during an interval is compared with an ideal useage rate. This ideal rate is established by the value of the non-sheddable loads and the maximum KWH that can be used without exceeding the demand. The rate will vary in each interval depending on the total load on line at the start. The demand interval reset pulse from the utility company activates the system's routine. When the difference between the actual consumption rate and the ideal rate goes below a predetermined minimum value, shown as the

shed line in Figure 2, the loads are shed. The loads are shed until the consumption rate drops below the shed line. The loads are not restored until the consumption goes below a second value shown as the restore line in Figure 2.

<u>The predictive principle</u>: The system is also synchronized with the utility company interval by the reset pulse. An ideal rate of electrical consumption is established in the same manner as described above. The loads are totalled and the energy consumption recorded. The interval is divided into a certain number of equally-spaced points. At each point, the current being drawn is used to predict the KW use at the end of the interval. The rate of consumption is computed. The projection of this rate to the end of the interval enables the system to determine if the addition of this consumption to the previously accumulated energy will exceed the maximum allowed. If the maximum will be surpassed, the excess KWH is computed and the amount of sheddable load needed to be dropped to stay within the limit is shed. Figure 3 graphically illustrates this principle.

<u>The instantaneous rate</u>: The rate of power useage is computed at random times. An ideal rate of consumption is set after considering the essential loads and the length of the interval to be set by the system. The current being drawn is used to measure the instantaneous rate of power consumption. When the rate is greater than the ideal rate,

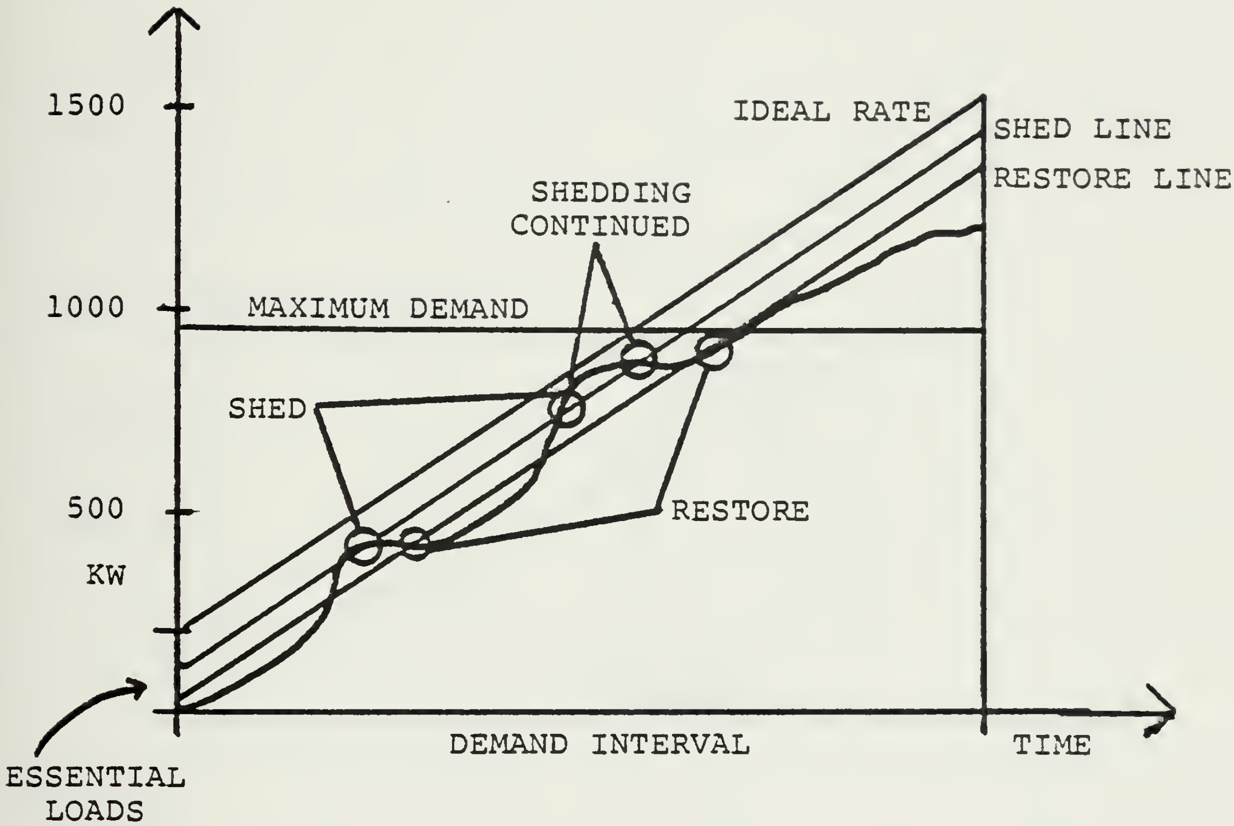

Figure 2. Ideal Rate Demand Limiting Method.

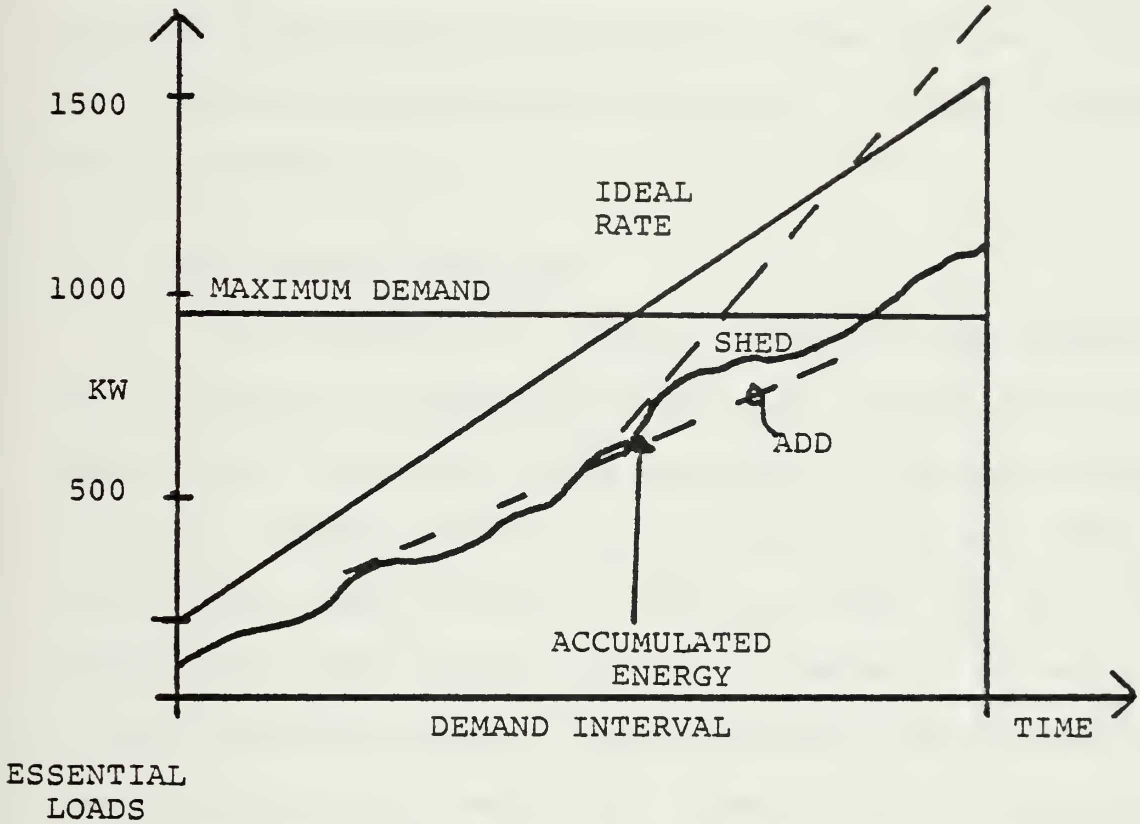

Figure 3. Predictive Principle Demand Limiting Method.

loads are shed until the rate decreases to one lower than the ideal. When the actual rate is less than the ideal rate by a certain preset amount, the loads are restored. The interval monitored is independent of the utility company demand monitoring scedule. The routine is not activated by the interval reset pulse. Figure 4 illustrates this principle [1, 14, 21, 27, 29].

F. CEMC System Functions

The functions of CEMC systems have been described as "a specific independent operational capability" by the Newcomb and Boyd Consulting Engineers of Atlanta, Georgia in their "Energy Monitoring and Control Systems (EMCS) Application Study Volume I" which was done for the U.S. Air Force. The CEMC system can be programmed to do many different functions such as the monitoring and controlling of many simultaneous tasks [20]. They can plan maintenance, optimize energy use, monitor security and life safety systems and many other tasks.

The functions listed below represent those available on most of the manufactured CEMC systems. The functions may be accomplished by hardware or software depending on the manufacturer.

1. Time of day controls: The starting and stopping of equipment is based on the time of day. It allows for limited operation of equipment and building systems at

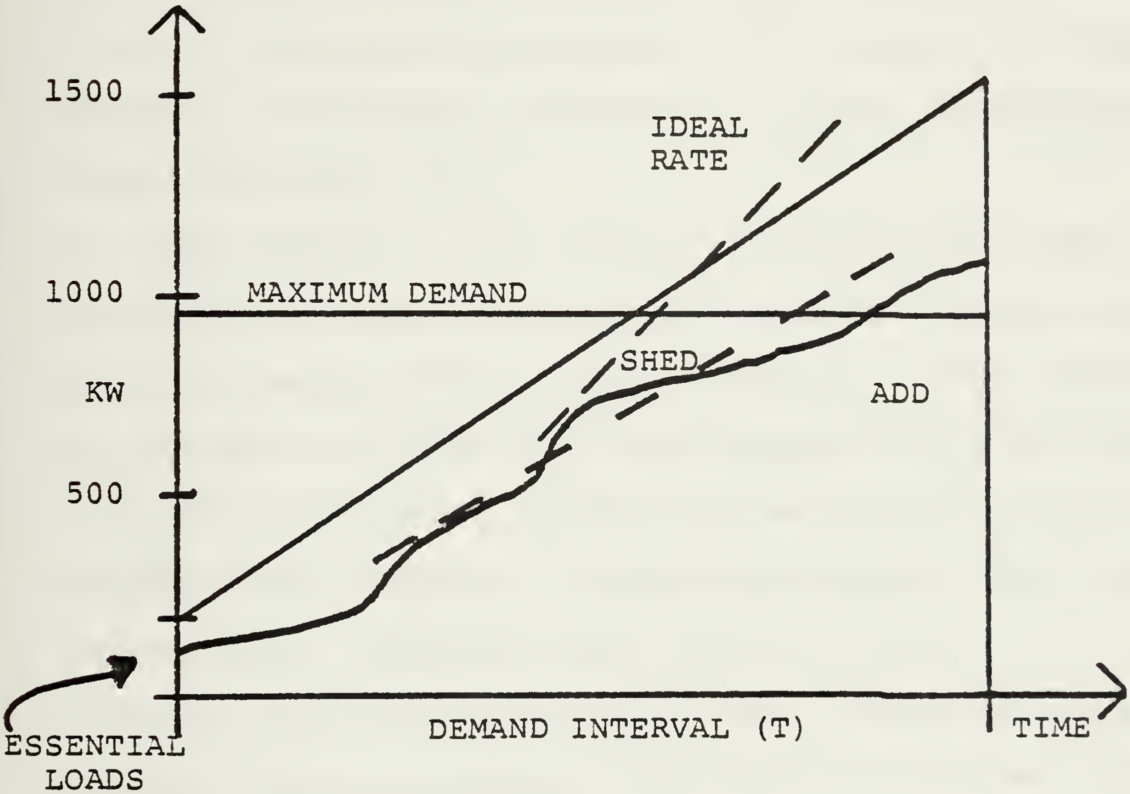

Figure 4. Instantaneous Rate Demand Limiting Method.

night and on weekends and holidays when the facility is not occupied. A time clock can perform this task, but the incorporation of this function into a computer-based system permits greater reliability and flexibility for modifications to the operating schedule. This routine can control lighting and heating, ventilating, and air conditioning (HVAC) equipment [14].

2. Duty cycling: Duty cycling is the shutting down of equipment for short planned periods of time during regular operating hours. It is usually limited to HVAC equipment. The concept is to shut off the equipment and allow the space temperatures to drift to the point where the system will operate more closely to its maximum capacity when it is reactivated. The energy for heating/cooling is not reduced, but the consumption by fans, pumps and other similar loads is lowered. The benefits of these energy savings must be carefully weighed against the increased wear and tear on the machinery. The fan motors and pumps are not designed to frequently cycle on and off. There may be more frequent breakdowns and the life expectancy of the machinery may decrease. The repair and replacement costs may exceed the funds saved by duty cycling [23].

3. Demand limiting: Demand limiting is discussed in an earlier portion of this chapter.

4. <u>Night temperature set back</u>: This function is designed to reduce heating costs by lowering the temperature set point when the facility is not occupied. The computer can be programmed to provide heat and ventilation to certain areas after regular hours. Only part of the equipment would have to be used, and controlling the dampers could seal off the vacant areas. Energy would be saved by not heating vacant spaces [1].

5. <u>Optimum start/stop of equipment</u>:

(a) <u>Morning warmup of building during heating season</u>: When the temperature is allowed to drift during unoccupied periods, the equipment should be started as close as possible to the occupied time. This prevents the building from reaching comfort conditions prior to being occupied. The start up time is computed after monitoring the inside and outside temperatures and comparing them to values stored in the memory. The stored data may be historical or based on the characteristics of the building envelope and the climate. In certain circumstances when the fluorescent lights can provide the heat to warm up the building, the system can determine if this will be more economical than igniting the boilers.

(b) <u>Morning cool down of building during cooling season</u>: The outside air dampers are positioned after evaluating the outside air temperature or enthalpy. If the outside air will provide the necessary cooling,

the chillers are left off and the fans are started. When needed, the chillers are started in a sequence that first activates the units that require the longest time to become fully operational.

(c) <u>Early shutdown of HVAC systems</u>: Near the end of normal operating hours, the system can determine if the HVAC system can be shut down prior to the vacant period. The inside and outside air temperatures and the building characteristics are considered to see if the structure will be able to maintain comfort conditions by virtue of its mass [1, 14, 27, 29].

6. <u>Enthalpy economizer cycles</u>: At certain times, the use of outside air can be justified to cool a building. The enthalpy or total heat content of the return and outside air is used to decide if the outside air economizer cycle will save energy. The enthalpy is calculated using the dry bulb temperature and the moisture content which is computed from the wet bulb temperature, relative humidity, or dew point temperature.

The air with the lowest enthalpy will require less energy to cool it to the space supply air temperature. At some times, the exclusion of outside air or the use of a mixture of return and outside air will be more economical. The proportions of each in the mixture is based on the ratio of their enthalpies. The result is that the air

supplied to the cooling coil has the lowest possible enthalpy [14, 29].

The use of enthalpy as the governing factor may give different results from the conventional method of evaluating dry bulb temperatures. James Y. Shih [27] gives six examples which are cited here to illustrate the possible differences.

Example 1.
Outside air dry bulb temperature = 95°F
Outside air dew point temperature =60°F
Outside air enthalpy = 35.4 BTU/lbm
Return air dry bulb temperature = 77°F
Return air dew point temperature = 55°F
Return air enthalpy = 28.7 BTU/lbm
Supply air dry bulb temperature = 55°F

In this case the outside air intake should be minimized since its enthalpy is higher. An evaluation of the dry bulb temperatures would give the same results.

Example 2.
Outside air dry bulb temperature = 75°F
Outside air dew point temperature =64°F
Outside air enthalpy = 32.3 BTU/lbm
Return air dry bulb temperature = 77°F
Return air dew point temperature = 55°F
Return air enthalpy = 28.6 BTU/lbm
Supply air dry bulb temperature = 55°F

The intake of outside air should be minimized since its enthalpy is higher. The conventional method of examining dry bulb temperatures would indiate the opposite result which would be false economy.

Example 3.
Outside air dry bulb temperatuer = 67°F
Outside air dew point temperature= 57°F
Outside air enthalpy = 27.1 BTU/lbm
Return air dry bulb temperature = 77°F
Return air dew point temperature = 55°F

Return air enthalpy = 28.7 BTU/lbm
Supply air dry bulb temperature = 55°F

Both methods would indicate that the use of 100% outside air would be economical.

Example 4.
Outside air dry bulb temperature =40°F
Outside air dew point temperature=35°F

Since the outside air is cooler than the space supply air temperature, a mixture of return and outside air would be used. The cooling coil would not have to be turned on.

The following conclusions may be drawn:

1. When the outside air enthalpy and dry bulb temperature exceed those of the return air, a minimum of outside air should be used.

2. When the enthalpy and dry bulb temperature of the outside air are below the values of the return air but above those of the coil air discharge, 100% outside air should be used.

3. When enthalpy and outside air dry bulb temperature are below those of the return and space supply air, outside air should be mixed with return air. The mixture should have the same characteristics as the air conditioning supply air.

4. These conclusions are not valid for dual duct or multizone systems or when moisture is added to the air in the space to satisfy a humidification load.

5. In dry climates, where the coil does not run wet and the outside air will have a higher enthalpy and lower dry bulb temperature the conclusions are not valid. Example 6 stimulates a dry climate where there is no latent cooling load on the coil. The use of the air with the lowest enthalpy will not always prove the most economical. Enthalpy optimization routines, in dry climates, should be carefully compared to dry bulb temperature evaluation routines to see which will be more accurate when determining outside air damper position.

Example 5.
Outside air dry bulb temperature = 80°F
Outside air dew point temperature = 57°F
Outside air enthalpy = 30.2 BTU/lbm
Return air dry bulb temperature = 77"F
Return air dew point temperature = 60°F
Return air enthalpy = 30.8 BTU/lbm
Supply air dry bulb temperature = 55°F

The use of 100% outside air is slightly more economical in this case. An evaluation of the dry bulb temperatures would not give the same results.

Example 6.
Outside air dry bulb temperature = 74°F
Outside air dew point temperature = 51°F
Outside air enthalpy = 26.6 BTU/lbm
Return air dry bulb temperature = 77°F
Return air dew point temperature = 46°F
Return air enthalpy = 25.8 BTU/lbm

100% outside air is more economical. When it is cooled, its dry bulb temperature = 55°F, dew point temperature = 51°F, and enthalpy = 21.9 BTU/lbm. 4.7 BTU/lbm of heat must be removed. The cooled return air characteristics would be dry bulb temperature = 55°F, dew point temperature = 46°F and enthalpy = 26.4 BTU/lbm. 5.4 BTU/lbm of heat would have to be removed. The higher enthalpy would require more energy for cooling.

These six examples show how enthalpy rather than the dry bulb temperature can achieve a greater savings of energy. [27]

7. Hot/cold deck temperature reset: A dual duct HVAC system simultaneously supplies hot and chilled air to a space where it is mixed to provide the required level of comfort. The operation is inefficient and consumes a great deal of energy. This consumption can be reduced by minimizing the temperature difference between the heating and cooling surfaces or "decks."

The interior spaces are monitored and the areas requiring the greatest heating or cooling are identified. The hot and cold deck temperatures are adjusted to the point where the difference between them is minimized and the supply air dampers to these spaces are fully opened to meet the demand. Control of the dampers to other spaces will mix the supply air so that it also meets their demands. The CEMC system is able to continuously monitor the space conditions and adjust the deck temperatures and damper positions to insure that comfortable conditions are maintained [29].

8. <u>Chilled water temperature reset</u>: The energy required to cool the chilled water leaving a refrigeration unit varies with the outflow temperature. Chiller units are designed to handle peak cooling loads. The temperature of the chilled water supplied at non-peak times is lower than is required to meet that cooling load.

The system can monitor the chilled water temperature and the position of the supply line valves. The temperature of the chilled water can be raised until the valves on the supply line are fully open. When this occurs, the chilled water temperature is meeting the actual cooling load. The higher chilled water temperature requires less cooling energy. The space cooling loads are satisfied so there is no loss of comfort. This same control scheme can be used to monitor the temperature

of hot water supplied from a boiler to reduce the heating fuel costs [14, 27, 29].

9. Cooling tower optimization: The optimum condensor water temperature supplied to a chiller depends on the atmospheric wet bulb temperature. The raising of the water temperature permits the shut down of certain pumps and fans. The resulting energy savings are realized while satisfying the cooling needs of the facility. While employing this routine, it is necessary to monitor the chiller so that the condensor water temperature is not raised to a point where the chiller efficiency is impaired. The system monitors the cooling needs, chiller efficiency, atmospheric wet bulb temperature and condensor water temperature and is able to calculate where the controllable parameters should be set to use the lowest amount of energy [14].

10. Optimization of chiller loading: In a multiple chiller system, the units may be piped in a parallel or series configuration to share the cooling load. Each individual unit has a load curve that shows how the energy use varies with the amount of thepartial load. The partial load data may be loaded into the system's computer memory. The computer examines the cooling load and the portion carried by each chiller. It redistributes the load among the chillers after comparing the partial load carried with the partial load curve. The units that are not secured are working as close as possible to their most efficient operating point.

The success of this routine depends on the availability of the partial load curves. Many chiller manufacturers will not release this data. The availability of this data should be explored prior to considering this routine. The partial load data, if known, will change as the machine components age and the refrigerant decomposes. The operation of each unit must be observed and the partial load curves revised on a periodic basis [14, 27].

This routine can be used to distribute the heating load among several boilers to optimize their loading.

11. Carbon dioxide control: Air quality parameters such as smoke and smells can be related to the carbon dioxide level. The quantity of outside air required can be based on the level of carbon dioxide present in the building. The system controls introduction of outside air, which must be heated or cooled, based on the actual need instead of standards stating the number of cubic feet per minute per occupant or square foot [14].

12. Gap control for self-heating buildings: Gap control allows the conditions in a space to drift between set limits. During this time, energy is not used to condition the space. During the heating season, the heat generated by the lights and equipment is circulated to the building's perimeter where conductive and infiltration heat losses require heating. The system can monitor the conditions in all of the zones and control the dampers

to circulate the warm return air in the proper quantity to the areas where it is needed.

The energy required is to circulate the air. The savings possible with gap control depend on the degree of discomfort that can be tolerated by the occupants. The space temperatures will not be maintained because the return air is not as hot as the normal heated supply air. The system must be able to override the zone thermostat's call for heat when it determines that the return air will be able to provide some of the heat [14].

13. Security: The monitoring, control and alarm functions used on HVAC systems can be used to provide security and access control. The addition of these functions does not cost much more money since the basic equipment will be installed for the HVAC system. The sensors and wiring are the only additional items needed if the system has programmable features.

Entry can be automatically controlled by the use of magnetic coding access cards and card readers, and keyboard type access panels. Each user is given a magnetic card or access code. The system is programmed to allow entry to certain user codes at certain times. The programming can also grant access to certain areas by the users. For example, if an individual has a card that will allow him/her entry to the building to go to

an office on the second floor, the system programming can prevent him from going elsewhere by not recognizing the code when the card is used in access panels for other areas.

The system is connected to conventional alarms such as motion detectors, infrared beams, and wire contacts on doors and windows. In the same manner that it scans HVAC systems for alarm conditions, the security devices can be read at the central console. A watch tour routine verifies that each station on the security guard's route is visited. The time between station checks ins is kept. If it is too long, the operator is notified that the guard is overdue. The guard's location can be approximated and a search may be instituted if desired.

Security functions can be easily added to the CEMC system that is being installed to control energy use. The small extra cost may be of great benefit to the owner, and may help to reverse an unfavorable benefit to cost ratio for a proposed installation [27].

14. Life safety functions: Life safety functions which monitor smoke detectors and fire alarm stations can be added to the CEMC system in the same manner as security functions. The additional hardware and software modifications are not complex and are compatible with the HVAC monitoring functions. The central control console is able to act as an annunciator which pinpoints the location of

the alarm. The software is able to activate exhaust fans and dampers for smoke control. The areas adjacent to the fire can be pressurized to prevent smoke from entering. The same procedure can be done for stairways to help keep them clear for evacuating personnel. The special control can be applied to the elevators to make them readily available for use by the fire department. The system can play pre-recorded messages that will inform the occupants of the situation and direct their evacuation away from the affected areas.

In certain applications the fire alarm system must be Underwriter's Laboratory approved and installed in accordance with the NFPA Life Safety Codes. An alternative is to have the system monitor the read outs from an existing system that meets these requirements. This can reduce the cost of the installation while keeping the benefits of centralized monitoring [27].

15. Building management: Building management functions include the logging of alarms for HVAC, security and life safety systems. The system can prepare maintenance summary reports. It can keep track of equipment operating hours and inform the operator when maintenance is required. The notification message can tell the operator what the maintenance work will entail. The data collected by the system can be processed to show the utility consumption and cost trends. Reports of this kind assist building

management in the prediction of costs and help to evaluate the effectiveness of the energy conservation programs.

The logging of occurrences and routine point data relieves the operator of this task. The logs are more accurate and less prone to human error. The computer scans the points more frequently than a manual method and the data collected is more accurate [1, 27].

16. Intercom: The CEMC system can provide voice communications between the central control console and the remote locations. When trouble shooting alarms this link can be of great value. The installation of the intercom should be weighed against the availability of alternate means such as telephones or a radio net [24].

The preceding list does not give every function available on all systems. The availability will depend on the manufacturer. These listed functions are those necessary for an initial standard application.

CHAPTER III

THE CEMC INDUSTRY TODAY

A. Introduction

There are many companies that produce Central Energy Monitoring and Control systems. This chapter examines some but not all of the CEMC systems which are available today from many manufacturers. The information on the various systems was provided by the various manufacturers. There is no evaluation of the systems. The order of presentation does not indicate the author's opinion concerning their quality.

In addition to describing the systems, the chapter contains the industry view on other issues relevant to CEMC systems. This information was obtained during interviews with the persons listed in Appendix A.

B. Honeywell Delta 1000

The Honeywell Delta 1000 Building Management System can be used in buildings as small as 100,000 square feet. It can function in all but the largest buildings or complex of buildings. It can be mounted on a wall taking up less than twelve square feet of space.

The CPU is a microprocessor based mini-computer. The random access memory is contained on plug in circuit boards. These can be added to the system as the need for

additional capacity develops. The CPU is controlled by the system's software. It does not have to be in the same space as the control console.

The operating system, which insures that the automatic monitoring and control functions are performed, is loaded into the system using cassette tapes. The operating system controls the commands to display the output on peripheral devices, the printing, and calculations in addition to the scanning and control functions. The data base is entered through the operator's keyboard. The operating system is written in Honeywell Delta 1000 Command Language which is a high-level language that requires no computer programming background to use it. The customer can modify the programming by following the instructions in a reference manual provided. The changes are made through the operator's terminal. The programs are protected by a multiple-level access code that prevent unauthorized persons from making alterations. The multiple level prevents major changes from being made by persons authorized to make minor adjustments.

The Delta 1000 has standard application programs. Their routines will perform all of the functions described in Chapter II. Two of the programs, the event initiated routines and Control Interpreter Language (CIL),

are tailored to the specific application. An event initiated routine might automatically start exhaust fans and call the fire department after a fire alarm signal is received. The CIL enables the user to modify or create new control sequences without a professional computer programmer. The application programs are modular and can be added when needed. The application programs can also be updated by personnel authorized by the user, using the guide manual and operator's keyboard.

The interface devices called Data Gathering Panels can connect several pieces of equipment to the CPU. There are special units for fire and security functions. All of the panel models operate in the same manner, converting analog impulses to digital signals and addressing commands to the attached sensors. The signals are transmitted between the Data Gathering Panel and the CPU using multiplexing techniques, via twisted wire pairs. The digital signals can be sent over telephone lines by connecting a modem to the interface device.

The data is transmitted twice. Each bit is compared for accuracy. The transmission lines are continuously scanned to allow instant notification of a break in the system.

The operator console(s) can be located for convenience. The console components may be matched in any needed combination. There are several different model

printers and operator's terminals available. A CRT with a keyboard and a graphics projector that displays schematic slides of the building and its systems can be added to the system. A peripheral control unit is used to interface the various devices with the CPU. Different consoles permit the level of sophistication to be tailored to the application.

The Delta 1000 hardware components are modular. They can be added to expand the system desired. Hardware that permits the Delta 1000 to be added to earlier Honeywell systems is available.

C. Honeywell Delta Distributed Control System

For large applications, where the Delta 1000 would not be adequate, the Delta Distributed Control (DCC) System, can be used. This system provides a distributed processing architecture. It connects two or more of the previously described Delta 1000 systems via a central bus to provide additional memory and point monitoring capabilities.

Each of the microprocessors in the individual Delta 1000 systems performs the control and monitoring functions independent from the Central Control Point. The systems can be arranged to coincide with the organizational breakdown of responsibility, such as running all security functions to the console in the security office, etc. The microprocessors are connected to a mini-computer which

can serve as a bulk data storage component or as the CPU to perform calculations. When it is used for bulk storage, an additional microprocessor serves as the central bus monitor. If one of the connected microprocessors malfunctions, only the points attached to it are affected. The remaining units continue their normal operations.

Each system is separately programmed. The modifications can be made to the software in the regular manner used on a Delta 1000.

The DCC control console employs a CRT with a keyboard and graphics projector. The printer can make hard copies of reports that are produced by preprogrammed routines in the operating system.

The DCC can be connected to other Honeywell systems that preceded the Delta 1000. The old wiring and sensors are reused. The DCC's computerized software capabilities are used to perform the more complex control sequences and optimization calculations.

D. Johnson Control JC 80

The Johnson Control JC 80 Building Automation System is designed to be used in a facility requiring a minimum of 200 points to be monitored and/or controlled. There are several models which have different capabilities.

The CPU is a mini-computer. It is combined with a fixed or moving head disc random access memory to perform the basic scanning and control functions provided by the operating system. By the addition of different components, the JC 80 can be installed in a distributed processing configuration.

The interface devices which are called Field Processing Equipment provide the link between the sensors and the CPU. Data is sent using multiplexed signals. The IDs can be used in the system's regular or distributed processing mode. The panels contain circuit cards which perform the usual functions such as analog to digital conversion. When the Field Processing Units are given a portion of the system intelligence, they are called Distributed Processing Control Units. An alternative distributed processing scheme uses a loop controller to coordinate the reporting by the remote processing units over the coaxial cable loop. The distributed processing capability does not include the ability of the remote processors to function independently of the central control point if the coaxial cable link is severed.

The communication system consists of a coaxial cable loop that connects Loop Remote Devices. These function as interfaces between the Field Processing Equipment and the coaxial cable.

The JC 80 operator consoles have printers, CRTs with keyboards and a graphics projector. There are two types of printers, one of which has a keyboard. An Integrated Data Display (IDD) which displays the graphic on a color CRT screen with the current point values next to their symbolic location is available. The console components can be arranged in many configurations.

The system software provides an English language display on the CRT and printer. If the operating system is a disc-based system, the operator can make changes using the reference manual. Non-disc based systems require the reprogramming for changes, such as the addition of a point, to be done by Johnson Control. The operator can change the application programs using the operator's keyboard and the reference manual. The application programs are modular and will perform all of the functions listed in Chapter II. The programs can be added to the system as the need arises. Both the operating and application programs are protected by a multilevel access code to prevent unauthorized changes from being made.

The JC 80 is compatible with earlier versions of the Johnson Control CEMC systems. It can provide additional capabilities and modern technology when combined with the older system's hardware.

E. MCC Powers S170/80

The MCC Powers S170/80 Energy Management system can be used in large or small facilities. It has a microprocessor based computer which is the Central Control Unit. The operator's keyboard is attached to a printer. The entire console including the Central Unit is small enough to fit on top of a desk.

Although it is small, the S170/80 has all of the energy and facilities management capabilities described in the preceding chapter. The messages are displayed in English. The operating and application programs are written in assembly language. The standard application programs pick up the data base through entries made on the keyboard. The owner is able to add extra points and modify system operations in a similar manner. The system parts can be added as the need arises.

The S170/80 has a distributed processing arrangement. A device called an Accensor which contains a microprocessor is attached to each field device such as a sensor. The Accensor is the only link between the sensor and the Central Control Unit. It contains programming for the scanning and control of its attached sensors, and the circuitry that enables the sensor to recognize its address. This arrangement is called a "smart sensor." These devices can be wired in a series

directly to the Central Control Unit. The data transmission is by multiplexed signals.

The S170/80 is a small system. A new larger model called the System 600 will be featured by MCC Powers in late 1979. It will be a computer-based system featuring standard owner programmable FORTRAN software. A color graphic CRT displaying actual point values, a digital computer, printer and other peripherals will be available. It will be a distributed processing configuration. The application programs will provide the previously described functions. The System 600 and the S170/80 will be able to be connected to earlier MCC Powers systems to provide updated technology without replacing the entire system.

F. Robertshaw DMS 2400-3

The Robertshaw DMS 2400-3 system is designed for a large single structure or a multiple building application. It has a distributed processing architecture. The interface devices or Field Control Panels contain microprocessors which can direct the scanning and control of the attached points. The data collected can be stored for transmission to the central control point when required. The only contact with the central point is when conditions change beyond the preset limits. If the twisted wire pair cable is severed or communications

with the central point are interrupted, the Field Control Panel will continue to function.

The central control panel has an optional color graphic projecting CRT which displays actual point data at the location on the graphic. This unit and the black and white CRT have a keyboard. A printer is provided to make written copies of the logs and other report data. Magnetic disc memory components can be added to the system as necessary to provide data storage for control and optimization calculations. The CPU is a microprocessed based mini-computer.

The application programs are written in FORTRAN. The operator may input changes through the keyboard. All of the building and energy management functions listed in Chapter II can be done by the DMS 2400-3. The operating system is in assembly language. It can be altered by a qualified programmer or Robertshaw.

G. The Industry Views

Some of the Central Energy Monitoring and Control System manufacturers' representatives were asked the questions in Appendix A. Their answers provide input which should be considered when dealing with these systems.

The manufacturers can connect their systems to those of their competitors. This is not done since the problem of responsibility for maintaining the different systems can arise. The cost of making the necessary

changes would not be justified for the limited number of times they could be used. Each manufacturer prefers to remove old systems that are not their own product and install a totally new system.

The manufacturers feel that the purchaser of a CEMC system is tied to the original manufacturer. The difference between the systems is the degree to which the owner must depend on the firm to change the system and keep it running.

If a facility is being designed and a CEMC system is being considered for a future project, there are things that can be done during the building design stage to reduce the future cost. The following items were recommended by the industry representatives during their interviews.

The area that will be the location for the central control panel and other hardware should be designated. It should be large enough to accommodate the equipment and personnel. Adequate ventilation that will meet the environmental conditions required by the system and its operator can be provided in the HVAC system design. Empty conduits should be installed in slabs and to other inaccessible areas to provide for the system wiring. In piping such as for chilled or hot water where the fluid flow or temperature values are to be measured, the sensor wells should be installed. The early

installation will eliminate the need to drain down the system and splice in these pipe sections, saving time and labor. All control hardware should be compatible with remote control applications. Extra contacts for controls, starters, and electronic sensors that will accept the CEMC system wiring will eliminate the need for relays. One manufacturer recommends hardwiring the controllers to an electrical panel containing contacts and pilot lights. When the system is installed the CEMC field panel can be wired to the first panel to tie in the points. If the system is never installed, the panel's pilot lights will act as indicators. If the lighting is to be controlled, low voltage control relays should be included in the electrical design. Motors should have hand/off/automatic (HOA) switches wired out to a block where the CEMC system can be connected.

H. A Final Note

The information given about the different manufacturer's systems is by no means complete. It is only to give a general view of the system. The choice of a CEMC system for a given job must be based on more complete information than is given here.

CHAPTER IV

A REVIEW OF CEMC SYSTEM APPLICATIONS

A. Introduction

The use of CEMC systems became more widespread after the 1973 oil embargo forced facilities managers to find ways to reduce energy consumption. Many claims are made about the cost savings derived from CEMC system applications. There have also been many problems associated with the installation of these systems. The questionnaire shown in Appendix A was sent to the facilities listed. This chapter discusses the results of this survey and the articles available in the literature.

It is recognized that the sample size is small, as only eleven out of eighteen surveys were returned. The results are not conclusive. There will be exceptions.

B. Problems

The period after the installation is completed is used to debug and fine tune the system to the actual building operating and climatic conditions. The time required to accomplish this can range from a few months to over a year. The complexity of the system and the size of the facility will cause the variation. In extreme cases, the system does not meet the owners'

requirements and it never runs properly. This is usually a design problem or a misunderstanding by the owner of what the system is supposed to do. These situations are discussed in the next chapter. The usual experience is for the debugging and fine tuning to last for approximately six months.

Only some of the problems are detected during the debugging, with others coming later. The most common problems are incorrect alarm signals that indicate a condition that is not occurring at that time, and printer problems. The causes of the incorrect signals were usually the sensors being improperly located or not calibrated to the proper range. The printer problems are caused by hardware breakdowns. The respondents feel that the frequency of breakdowns was not excessive in comparison to other mechanical equipment. Some of the installations experienced difficulties getting the system to automatically restart after power supply interruptions. Operator errors are another frequent source of system malfunctions.

The survey revealed that system reliability is quite high after the break in period. The breakdowns occur approximately once in six months. One user reported that the system was on line for 96% of the time. Another stated that the system had never broken down and admitted that their experience has been unusual.

The reliability of CEMC systems is comparable to other building systems.

The trend is for larger customers to purchase their systems in phases. The central hardware is purchased and only part of the facility or the desired functions are connected. After the first phase is operating properly, the owner expands the system until all of the needs are met. Expansion has been a problem because many owners have found that they can only obtain the hardware from the original manufacturer at an exorbitant price.

As stated in the previous chapter, the industry representatives stated their belief that the owner would always be tied to them in some degree. They believe that their systems are designed to minimize the degree to which the customer must return to the manufacturer to make changes and expand the system. All but one of the survey responses, which indicated that they had attempted to expand their systems, answered that they had to go to the manufacturer to accomplish the work. The dependence was limited to the purchase of hardware such as sensors and field panels. Some of the institutions answered that they had to hire an outside programmer to modify the operating system. The others reprogrammed the system themselves.

Sometimes the maintenance of the system causes problems. With the exception of two installations, the availability of parts and maintenance was not considered a problem. The performance of maintenance by service contract and operator personnel was evenly divided among the responses from the satisfied customers. One of the unhappy firms cited an annual contract price of $70,000 for a system covering 58 buildings and 2,000,000 square feet. The cost did not include the value of the work which was done by "in-house" personnel. The other report of maintenance problems was from an installation that is totally dissatisfied with their system. They feel that it is not adequate for their needs. If the owner is aware of the cost for maintenance, there seems to be little problem maintaining the systems. The industry adequately supports its product.

In retrofit applications, not all of the existing building system devices are compatible with the new system. In two of the cases surveyed, the manufacturer provided the hardware in the contract price. This is the exception and most customers have to purchase the new controllers, valves and sensors. This cost is in addition to the basic CEMC system price.

A problem that will be explored in more detail in the next chapter is the owner's perception of what the system can do. Sometimes the manufacturers build up

the expectations beyond the actual capabilities. The accounts of this problem are more common in the early CEMC system applications. The more recent articles and the survey results show that the owners are satisfied with the system's actual performance when compared to the pre-installation projections. Three of the eleven responses showed a belief that the system was oversold. However, two of the three dissatisfied customers indicated that the manufacturer worked with them to help utilize the system more effectively after the break-in period.

It is the author's belief that the system capabilities are usually accurately portrayed. Any errors can be attributed to overzealous sales personnel and a lack of knowledge by the owners and their design team.

C. Benefits

CEMC systems can reduce utility charges and increase the efficiency of the building labor force. The inclusion of maintenance routines can insure that work is not forgotten until a costly breakdown occurs. The monitoring frees maintenance personnel from inspections and allows more time for preventive maintenance.

The data collected by the system can be produced in many formats for use as management reports. The data is always up-to-date and gives management instant feedback on how its programs are affecting the facility operation.

The central console allows a single person to monitor and control facility operations. All of the survey replies except one indicated that a single person was operating the system. The exception reported no one manning the console. The operator can dispatch repairmen to investigate and correct alarm situations. The concentration of control and monitoring at a central point is a viable concept that works.

The major advantage of CEMC systems is the reduced use of energy. Proper applications of the technology have reduced costs to the extent that the cost of the system installation was recovered in less than three years. An initial energy audit should predict the annual savings. Operating and maintenance as well as the labor and energy savings must be included in the economic analysis. The simple payback of the initial cost divided by the annual savings is used to determine the amount of time required for the system to recover its cost. The value of capital and the escalation of costs are disregarded.

The predicted savings are accurately forecast by the companies. Analysis of the responses show that the actual cost savings are greater or equal to the projection. The approximate mean of the responses was three years for the payback. The figure is not an absolute since some of the systems have not been operating

for a year, and the answers given result from the extrapolation of early data. The dissatisfied customers show paybacks exceeding five years for installations that do not seem to function properly. In another smaller application, the installation paid for itself in less than one year. It was a system monitoring and controlling two buildings consisting of 275,000 square feet. The proper application of a CEMC system can save sufficient energy and labor costs to pay for its investment in three years or less. The continuous rise of energy and labor costs will reduce this figure.

The personnel working with the CEMC system will develop trust and faith in it after a period of use. The initial doubts may be related to past experience with automatic control systems that did not perform as well as expected. The fear that the system will eliminate jobs as it saves money can cause personnel to resist using it. In most cases, the fears and doubts vanish as the people become more familiar with the system and its operation. They use it and rely on it to do its job. It is accepted as a tool of their trade to be used like any other. The single application where the personnel expressed a distrust of the system is the one where the entire organization is not satisfied with the system.

D. Conclusion

A perfect installation of a CEMC system is rare. It is safe to say that if the system is properly designed and installed, and has not been overrated as the cure-all for facility problems, the benefits to be derived will exceed the problems. The best indication of the success of the CEMC systems is that all of the respondents recommend the installation of a system in a similar facility. The proper investigations to be done during the design stage are discussed in the next chapter.

CHAPTER V

THE SPECIFICATION AND PROCUREMENT PROCESS

A. Introduction

Central Energy Monitoring and Control systems vary in size, complexity and capability. The complexity of these systems has caused problems when the normal construction procurement process is used to develop plans and specifications and seek competitive bids. These problems require that changes be made to this traditional method. This chapter explores the problem and some solutions that have been proposed.

B. The Problem

Numerous problems arise when regular specification and bid procedures are used for CEMC systems procurement. A standard construction specification is written to insure compliance with certain established physical criteria such as strength, durability, etc. The use of physical criterion to evaluate CEMC systems is not practical. There is a need for a new type of specification for use in their procurement.

Before the specification problem can be examined, there are more basic problems which must be understood. The lack of a commonly-defined terminology causes difficulty for facility owners, design engineers, and the

CEMC system manufacturers. There are no standard, universally accepted definitions for the terminology associated with CEMC systems. There is ambiguity and much latitude for interpretation errors by the many parties involved in the design and bidding.

The consulting or design engineer has the problem of trying to understand and specify a new technology with which he is not familiar. The terminology problem adds to the diffuclty. The engineer's design fee schedule places an economic limit on the time that can be spent on learning the CEMC terminology. Since the system is only part of the design responsibility, the usual approach is to contact one of the manufacturers to obtain their standard hardware or "boiler plate" specification. The engineer is unable to put in the time to edit the specifications into a single document that contains the best portions of each. The specification from the manufacturer is usually biased in favor of his system. This specification is incorporated into the contract documents that are used by all manufacturers to submit "competitive bids."

When these bids are reviewed, the engineer and owner are not familiar enough with the technology to evaluate which system is the best buy for the funds expended. In the absence of other criteria, the lowest priced system is chosen. This can be false economy since

the systems may have different capabilities and features. The second lowest system could be superior to the low bid, and only cost a small extra amount of funds. Since the prices are for different items, the use of the lowest price is not a practical way to select a CEMC system.

The terminology and vague specification problems make it difficult for the CEMC system manufacturer to submit a bid. The use of the low bid as the selection criteria, requires the manufacturer to consider what the competition will be bidding. The least sophisticated, lowest cost system is bid. If the specification is sufficiently vague, the manufacturer will be awarded the job. The facility owner receives a system that does not meet the expectations [10].

In this case one of two things will occur: 1. The owner will have to pay more money for contractual change orders to add the capabilities that were supposed to be in the original contract. The owner is usually upset with the designer and the manufacturer who is designated as a villain out to cheat the owner. 2. The system does not perform resulting in no savings in labor and energy costs as originally projected. Again the owner feels cheated and is wary of using the system or undertaking a similar project.

The general public believes that a computer is an intelligent machine that has unlimited capabilities.

The use of the computer for building control and energy management is seen as a cure for all facilities management problems. The problems described above result in many improper applications of CEMC systems. The misapplication of CEMC systems has thwarted their wider application since one story of unfulfilled promises makes potential users more cautious. The cost effectiveness is suspect and funds may be allocated towards less effective solutions.

C. Some Proposed Solutions

The specification and procurement problems detailed above were caused by the wider use of a new technology. The design engineers have recognized the problem and have started to develop some solutions to this problem with CEMC systems.

William J. Coad [7] in a discussion about CEMC systems develops a list of what he considers necessary factors to be studied during the design of a CEMC system. He explains why they are included.

1. CEMC systems must be used in areas where the sensors and transmission modes are known to be accurate. The selection of sensors must be governed by the performance and accuracy required. The communication links must be reliable since important data such as alarm signals cannot be delayed or altered by interference. The data

collected and transmitted is the base on which the system is built.

2. The system should be programmable. If the logic cannot be tailored to the specific application, hard wired circuit boards must be used. This restricts the addition of new components and technology to those produced by the original system manufacturer. It also limits the ability of the system to be adapted and expanded to meet changing conditions.

3. The system programming should be done by or in close cooperation with the system designer. The designer is forced to develop the operating logic, which should reveal flaws in the intended design. An independent outside programmer who is not intimately familiar with the system might not uncover a potential problem.

4. The system will have to be properly maintained. To facilitate this, it must be easy to perform the work. The lack of routine maintenance, or the improper performance of this work will decrease the system's reliability. The time that a system is not working deprives the user of its benefits and can cancel the potential savings. A decrease in reliability can cause the operating personnel to lose confidence in the system's capabilities [7].

Thomas M. Reinarts [23] recommends that the first step that must be done is an economic analysis of the

potential savings. To accomplish this, an energy audit, which evaluates the building envelope, the people and equipment loads, the climate, and which equipment can be controlled by the system to realize any projected savings, must be done. It is important to include the annual maintenance and operating costs as expenses which must be subtracted from the savings. Maintenance and labor savings are secondary, but should be included in the analysis. Once the feasibility and cost effectiveness of the system have been established, the design and specification work can begin.

The existing facility must be completely examined. The existing control systems for the HVAC and other systems must be defined. The designer must know what controls are in use and understand how they work. The compatibility of these controls with the proposed system must be evaluated. An example would be the presence of outside air and return air dampers when considering the use of an outside air enthalpy optimization cycle. If the building is equipped with dampers, the routine can easily be implemented. If fresh air ducts and dampers must be installed, it will cost more money and increase the economic payback period.

The controls and operating schedule for the individual equipment must be reviewed. If, for example, the

scheduling of operating hours during low demand periods, or a larger variation in the space temperatures can produce savings, the designer should investigate what controls exist or are needed to enable these actions to be supervised by a CEMC system.

Once the energy saving areas are identified, the level of system sophistication can be determined. A system from one of the levels described in Chapter II can be selected. It is important not to choose a system that has more capabilities than are needed. If it is too complex, it will be harder to place and keep in operation. The unneeded functions which will be used in the future are better added at that time. There may be new technology available which can do the job more efficiently.

The bid documents must clearly define and specify the system. A summary list of each point to be monitored and/or controlled should be made. For each point, the hardware required to accomplish the connection to the CEMC system should be identified. The cost of the connection should be estimated. The predicted savings from the monitoring of a point can be weighed against the installation cost. In situations where portions of a system must be deleted or deferred by budgetary constraints, the points with the longest payback or smallest benefit can be deleted until funds become available.

The project drawings should clearly delineate what the specifications require. A flow diagram which shows how the major components relate to each other and fit into the system is a necessity. It shows which components are connected together. It is intended to give an overview of the entire system and how it should function.

The trunk wiring diagram depicts the present and proposed data communication links. It will point out where the old and new systems will tie together. The elements of each will be shown so that there is no question of responsibility for maintenance and repairs.

A point schedule will completely list the equipment and functions at each point. The description should include the equipment function, and the controls installed such as run status indicators, reset controllers, and monitoring and alarm sensors. This drawing should summarize all of the information from the other drawings, the specifications and the description of the CEMC functions. It is included in the drawings since they are more likely to be retained than the specifications. This schedule will be needed for future expansion and troubleshooting.

A functional layout of the central control area should be drawn. The purpose is to see if the equipment will require too many people to work in too small an area. The drawing is not complicated and can prevent serious problems after the installation is under way.

The general location of the field hardware should be depicted on one drawing. The exact location should not be designated to allow the contractor to choose the most convenient and least costly site. The general location gives the installation the benefit of the contractor's experience which will usually be more extensive than the designer's.

The location of building equipment must be shown on general floor or site plans. These drawings help to clarify the job and provide a final check to insure that a point is not omitted by accident. It is also a convenient reference for trouble-shooting or when considering system expansion.

The trend is for specifications to be performance oriented. Instead of telling what equipment is to be included, they require a system to do certain functions. There are closely-defined standards which ensure that the performance of all of the components will be compatible.

The specifications should clearly define which functions the system must perform. They must be tailored for each job. If this is not done, the system will not perform as intended by the owner and designer. The use of a general specification can leave some ambiguities that can increase the project's cost or construction time. Statements such as "A system must be complete and

operable" is not adequate. To state that a device must be able to turn equipment on and off according to a schedule is not specific enough. In this case, a time clock will do the job. But it may not perform like the central computer system, which can be programmed with the building's schedule, and was intended for procurement by the owner and designer [23, 24].

A flexible system can perform more functions and be expanded as needed. New technology that is developed can be added. Flexibility is attained by the use of software programs instead of hardwired logic circuits. Since the flexibility and total system performance will be governed by the software, its specification must be carefully written.

Walton N. Hershfield has recommended that the designer: 1. Prepare a preliminary address list for inclusion in the specification. 2. Decide on an English language or assembly language format. 3. Require the vendor to detail how the program is loaded into the system. 4. Require the manufacturer to provide address lists for customer study and review. 5. Require the vendor to quote the price of making minor modifications to the system functions. 6. Require the vendor to quote the maximum amount of time that it will take to change the programs [13].

The analysis of the points to be monitored will develop a list of the needs that a system must meet. The

evaluation of these needs will allow the system to be sized. Once it is sized, the software which will direct the point scans and the data transmission systems can be specified since the frequency of the scans and the baud rate of the communication link will be known.

The use of an English language format instead of assembly language application programs simplifies the operator's job. It does require the use of more memory core, a longer print-out time, and a more sophisticated executive software program. It permits the display of messages and alarms in simplified language that does not require the use of reference or "go by" manuals. There is less chance of an operator error. These trade-offs should be presented to the owner for a decision. Once it has been made, the engineer must be sure to give suffcient detail to ensure that they are included [13].

An access code that only permits authorized personnel to make changes to the software must be required. There can be several levels that allow certain people entry into limited areas of the software. This arrangement can prevent the maintenance department from accidently modifying the security functions.

The degree of accuracy for the sensors and transmission lines must be specified. The calculations performed on the data collected will be affected by the error introduced by these components. The error is

additive, and the total system error percentage is more important than that of the individual parts. It should be stated. The required degree of accuracy should not exceed practical limits. The maintenance of eight-place accuracy in the transmission of a temperature value is not practical since the thermometer will not be able to measure the value to eight significant places, and the decimal points will not greatly affect the value of any calculation. But in the case of a digital push button entry panel, the loss of any digit would defeat the purpose of the security access system [24].

The specification of the accuracy, the size of the system and the speed and frequency that the points must be scanned will affect the selection of the data transmission links. The data transmission rate, signal accuracy, and quality must be specified to prevent the use of low-quality telephone pairs in a situation that requires the use of coaxial cable. The error rate and how many bits in the signal will be checked to verify accuracy must be clearly stated.

The arrangement of the control panel must be described in fine detail. The first decision required is the number of control panels to be installed. The locations of the various panels will dictate the distribution of the data among the consoles.

The control console must allow orderly communication between the computer and the operator. If it does not, the benefits of computer control will be lost. The required special keys for the print-outs of alarm summaries, access control logs, all point data logs, etc., should be listed. The information that is to be provided by each key should be described in detail to prevent incorrect assumptions by the bidders.

Since CEMC systems are very complicated, the specification should require a detailed system check out, debugging, and operator training program. Although the hardware will be checked and the software debugged at the factory, a point-by-point check of the installed system should be required. The extent of the check-out should be written in the specification. The procedure should be detailed and include a requirement for personnel to be at the remote points and the central console to verify the values read and the control functions performed. The calibration and point setting operations should be written up in a report that tells what was done and under what conditions it was done. This record should be retained for trouble-shooting.

The training of operators should be included in the specification. The first experience should be gained during the debugging and system check-out. This will expose

the operators to the system and some of the problems that may be encountered. The operators' skill will increase with time, and follow-up sessions should be required to help them fine tune the system to the building. Failure to provide for these sessions could cost the owner additional money for training that will help utilize the system more effectively.

After the system is debugged and running properly, the maintenance must be given proper attention. The specification for the system acquisition should consider the future maintenance. The inclusion of diagnostic programs for each system component should be written into the software specifications. These routines alert the operator when equipment efficiency decreases in relation to its normal operation or ideal rate curve. The equipment can be checked and tuned up. The wiring diagrams for all of the equipment should be required to be included in the literature package turned over to the owner.

Maintenance can be performed by the owner's personnel or by a separate maintenance service contract. The number of skilled people available, their salaries, the cost and storage space available for spare parts, and the ability to exercise proper inventory control must be weighed prior to deciding on the use of contract or force account personnel.

Maintenance service contracts should be competitively bid. The specification must be well-defined to ensure that each component receives the required type of maintenance. The maintenance requirements of each part should be written out to avoid any chance of neglecting a part of the work. If the installation contractor will not be performing the maintenance, the service organization should be selected prior to debugging the system. Once selected, it should be included in the debugging process so that the benefit of the early experience is obtained. Since long down times will reduce the benefits and cost savings from central automated control, the maintenance organization must be able to respond quickly to failures. It must be able to keep the system operating [26].

D. Actual Solutions

The ideas proposed above have not been tried in the field. Other similar proposals are to add a seventeenth division to the present sixteen in the Construction Specification Institute Uniform System. This division would cover control systems and would be written for performance rather than hardware quality. The many ways to perform CEMC functions using hardware, software or a combination of each would enable a performance-oriented specification to open the market to new innovative ideas.

Other ideas have been tried with mixed results. David W. Galehouse [10] relates an alternative specification and bidding strategy used for the installation of a CEMC system in the Miles Laboratories Elkhart Indiana complex in 1974.

The specification was written recognizing that each manufacturer's system control concept was different. The minimum system configuration was not the same for each due to a different role for the computer, communication techniques, etc. Some had a computer with an English language capability that flash complete messages on a CRT. Other computer-based systems use assembly language which only permits the display of a code which must be looked up in a reference book. Some systems do not use a computer. In spite of these differences, the systems are able to perform the basic functions such as scanning, annunciation and logging of alarms which operate in similar manners. The response and accuracy are about equal. The added-on features such as printers, CRTs, graphic projectors, and English language capability vary with each system.

The specification was written so that each company could bid their own system and show its individual features that exceed the specification. The differences among the competitors would be shown and the system selected would be the most for the money spent, not the lowest price. There was no base bid. The bid alternatives

were organized as shown in Table I. The alternatives specified each system by name and manufacturer. The system hardware and capabilities were completely described. The description was broken down into the categories and sub-categories shown in Table II.

The specification was written for the minimum acceptable system. Some of the bidders criticized it since the systems did not have to be comparable to be considered. However, it did not prevent the submission of a proposal for a more capable system that might have included an English language format or graphic projector. Mr. Galehouse concedes that it must be made clearer to the manufacturers that the alternative bids are desired and will be evaluated.

The proposals were evaluated by attribute scoring. This method has three steps: 1. The system needs are prioritized and stated. 2. The features which will help the system meet the needs are defined. 3. The ability of the different CEMC systems to meet the needs is scored.

This method accomplishes four important objectives: 1. The needs and priorities are redefined after the preliminary proposals are given by the manufacturers. The "extras and nice to have" features are identified and classified within the priorities previously set down.

TABLE I

LIST OF BID ALTERNATES

I. General Description
II. Sub-System Description
III. Functional Description
IV. Control/Monitor Point Schedule
V. Sensor Quality
VI. Job Engineering and Supervision
VII. Training
VIII. Guarantees

TABLE II

ORGANIZATION OF THE SPECIFICATION

I. General Description
   A. Equipment Monitoring
   B. Command Capabilities
   C. Fire Detection and Alarm
   D. Security Alarm
   E. Audio Communications
   F. Emergency Power Monitor
   G. Future Capabilities
   H. Programming
   I. Momentary Power Interruption

II. Sub-Systems Description
   A. Central Console
   B. Printer
   C. Graphics System
   D. Data Gathering Panels
   E. Digital Communication System
   F. Intercommunication
   G. Sensor Wiring
   H. Power Wiring
   I. Ventilation Fans

TABLE II

ORGANIZATION OF THE SPECIFICATION
(Continued)

III. Functional Description
   A. Analog
   B. Analog Alarm
   C. Digital Status
   D. Digital Alarm
   E. Two and Three Mode Control
   F. Control Point Adjustment
   G. Start Stop Programming
   H. Report Options
      1. Automatic logs
      2. Alarm Summary log
      3. Status Summary log
      4. Single Group log
      5. All Points log
      6. Totalizer log
      7. Trend log
   I. Graphics System

IV. Control/Monitor Points Schedule

V. Sensor Quality
   A. Temperature
   B. Pressure
   C. Humidity

VI. Job Engineering and Performance

VII. Training

VIII. Guarantees

It prevents the owner and design team from becoming too enchanted with a special hardware feature that does not enhance the system's ability to perform the desired functions. The result of such enchantment can be a system consisting of nice-looking gadgets that does not do the job. 2. An unbiased evaluation of the proprietary systems in comparison with the facility's needs can be made. 3. The unique feature of one system does not influence the final selection more than it should when weighed against the needs. 4. A formal recommendation is developed for presentation to the owner.

This specification and scoring system was successfully used to install the first phase of a five-phase program that would eventually automate twenty-six buildings at the Miles Laboratory Elkhart, Indiana complex. In spite of the success, some problems were encountered. As previously noted, not all of the manufacturers realized that alternative proposals were being sought. The recommendation is that a sentence clearly stating this policy be placed in the general description of the work, and in the bid information.

Projects using software to minimize energy use, must clearly define optimization for each function in which it is used. The systems and equipment to be optimized must be listed. Constraints such as the maintenance of a

certain level of comfort must also be made clear. The savings anticipated should be checked to insure that the proposed strategy will work properly with the sensors and communication links specified [10].

Mr. Galehouse does not give details on the amount of expertise available at his firm or in the client's staff. It seems that the use of this scoring system would require an owner and designer with more than basic knowledge of CEMC systems to determine the needs and priorities.

Another trend being pursued in the specification of CEMC systems is the development of "boiler plate" or "type specifications." The intent is for them to be used as a starting point for the definition of any system by deleting the unnecessary clauses. In late 1976, the United States Air Force wrote the first draft of a CEMC system guide specification. It was presented to the other armed services for review and revision. Conferences attended by the Army, Navy, Air Force, and later the General Services Administration (GSA), and the National Aeronautics and Space Administration (NASA) were held to update specification for government use. The most recent edition was published in August 1978, and will be revised after field experience with its use is obtained. The contents of this Government or Tri-Service specification are described in Appendix C [32].

E. The Manufacturers' View

The question of CEMC system specification and procurement was posed to some of the system manufacturers. All agreed that there is a problem. They expressed some preferences for different bidding strategies and specification practices.

One manufacturer proposed the two-step proposal system. The first step is for the consulting engineer to determine a list of desired functions. The manufacturers are invited to submit bids on the list. The engineer evaluates the bids and determines which features represent the most beneficial system. The manufacturers are asked to give the cost of the items not included in their original bid. The engineer has the cost of similar systems that have the same capabilities and hardware features such as CRTs and printers. It helps to eliminate the problems caused by attempting to compare "apples and oranges."

The wording of the specification was not agreed on by the different people interviewed. The first view was to be specific and define what you want the function to do. There should be minimum standards of performance, a review of the firm's past performance, and verification of the ability to provide training and service. The standard is included to prevent unreliable temporary firms from bidding jobs beyond their capability. The

specification can be obtained from one company, but the engineer must modify it so that it is not biased in favor of that firm.

Another view was that the specification should be written in vague language that allows the bidder a great deal of leeway. The objective of the system such as labor or energy savings should be outlined. The control company should be allowed to tell the owner how to accomplish the system objective. The individual who proposed the idea concedes that there could be a problem in trying to evaluate the dissimilar systems. But, he felt that it would not be any worse than what is presently being done.

The manufacturers agreed that the specifications should be functionally rather than hardware oriented. They favored the submission of proposals for evaluation at bid. The procurement by competitive bids was not favored. The consensus is that the owner and designer must be knowledgeable about the product being purchased. One recommendation was to examine the firm's standard systems, identify the one that will do the job, and negotiate a price.

CHAPTER VI

A CEMC SYSTEM FOR THE UNIVERSITY OF COLORADO, BOULDER

A. Introduction

The application of CEMC systems in large building complexes has been successful. Among the users have been college and universities in all parts of the United States. In 1970, a survey of the Association of Physical Plant Administrator members performed by the University of Montreal Physical Plant Department found that 74 campuses had a CEMC system operating, 74 campuses were installing a system and 74 institutions were planning for an installation. More than 80% of those with operating systems reported savings in energy and maintenance costs.

Originally experience had shown that 2,000,000 square feet was required as a minimum to justify a system installation. The mini-computer and use of standard modular software systems have reduced acquisition costs and the break-even point by a factor of four. An alternative general rule was to have a minimum of 400 to 450 points to be monitored.

B. Other Campuses

The University of Minnesota has had a CEMC system since 1960. The original system has been expanded and modernized to its present size which covers 100 buildings

enclosing 10,000,000 square feet. The annual direct and indirect savings were estimated at a half a million dollars in 1974. They were expected to grow and level off at a million dollars annually. The estimated pay back for each phase of the system was three years or less [8].

The University of South Dakota has the first phase of a CEMC system installation in operation. It monitors and controls 31 buildings containing just over one and a half million square feet. The predicted cost savings were equal to those actually achieved. The school estimates the pay back will take approximately five years. The system had some initial problems which kept it out of operation for the first part of the evaluation period. The estimated one million dollar cost of replacement of the existing controls and devices and the ten thousand dollar annual maintenance cost are lengthening the pay back period. In spite of the problems, the University recommends the use of a CEMC system, and did not indicate that the other phases would be delayed or cancelled.

C. The University of Colorado, Boulder

The University of Colorado (CU) Boulder campus contains approximately six and a half million square feet in 274 buildings. Approximately 55% of the floor space is in 75 buildings which are funded by appropriations from the State Legislature [9].

During the past ten years, many studies have been made concerning energy conservation measures at the CU campus. The ones relevant to the proposed CEMC system installation are:

1. In 1969 the Honeywell Corporation investigated the existing building mechanical and control systems. A recommended CEMC system would start with 700 points and expand in phases to 3,000 points.

2. The Police Department and Physical Plant have looked into several methods for expanding fire and security alarm reporting. The creation of a central reporting location was included in the studies.

3. The Universities Service Department has had a continuing program to reduce the quantity of leased telephone lines required to transmit fire and security alarms.

4. In 1973 Swanson-Rink and Associates, Consulting Engineers developed a master plan for a CEMC system installation on the Boulder campus. The system emphasized security applications which were most important at that time.

5. In 1976 Carr and Dow of the University's Department of Civil, Environmental and Architectural Engineering studied and updated the plans for installation of a CEMC system on the CU Campus. The first phase which was given in detail would connect 443 points. The report developed a six-phase expansion program that would follow

the initial 1977-78 installation and end during the 1983-84 school year.

6. In 1978 Epps of the Civil, Environmental, and Architectural Engineering Department developed an energy conservation program and a plan for its implementation at CU. The advantages of a CEMC system installation were summarized from the Swanson-Rink Master Plan as:

A. Security: A CEMC system has the capability to tie together all security and safety systems throughout the campus by electronically monitoring remote areas.

B. Fire Protection: A CEMC system can report a fire within a building to a central point.

C. Critical Environmental Functions: A CEMC system can monitor critical environmental variables such as temperature and humidity that must be maintained in warm and cold rooms located in the Bioscience Building and other critical research areas on campus.

D. Preventive Maintenance Program: A CEMC system allows maintenance of equipment to be scheduled on a preventive instead of a breakdown basis. Also, a CEMC system can assist with the cost-management control of such a program.

E. Equipment Status Check: A CEMC system provides monitoring and adjustment from a central point for things like key temperatures, pressures, humidity, equipment status and alarm conditions. Central monitoring provides

a quicker response to potential problems as well as reducing manpower requirements for the periodic inspection of buildings.

F. Equipment Start/Stop: Equipment such as fans, pumps, compressors, etc., can be started or stopped from a central point. Programmed start/stop can be made to conserve energy. Equipment start-up after power failures is simpler if done from a central point.

G. Campus Intercommunication: Trouble-shooting can be done in the central control area and the instructions sent over the intercom to personnel doing the work.

H. Leased Line Cost Reduction: A CEMC system would use its own data transmission links, eliminating the need for leased telephone company lines.

I. Central Lighting Control: A CEMC system can control interior and exterior lighting from a central location.

J. Energy Conservation: A CEMC system permits the operation of equipment on a time adjustable control basis. Systems are operated only when needed to reduce energy consumption. The heating water temperature, hot and cold deck air temperatures, etc., can be monitored and adjusted from a central point to coincide with the outside air conditions [9].

All of the studies have shown that a CEMC system would benefit the CU Campus. If properly installed and

utilized, it could pay for itself in three to five years.

The constantly changing technology, especially the use of microprocessors and standard software programs has helped to contain the rise of system costs. New systems with a distributed control format are ideally suited to a multiple building situation like the CU Campus. A separate microprocessor will monitor and control its attached sensors and equipment independent of the central control point.

The microprocessor and modular features of the distributed processing systems allow them to be expanded at a lower cost than in the past. The new systems and technology are designed to utilize earlier models' hardware and in some cases the software. The previously installed systems do not have to be scrapped, but are a base for a new system.

The report done by Epps raises the question of whether it is better to wait for the new technology before installing a system. As stated before, the new technology can be added to the older systems. The different proprietary systems cannot be combined. The manufacturer's representatives feel that the evolution of the technology is gradual. The hardware costs are remaining constant or rising very slowly. The cost of system

installation is rising due to the labor costs for installation. The current rise in energy prices is not expected to slow down. The postponement of the installation of a CEMC system in the anticipation of a new technological breakthrough deprives the user of the benefits of central monitoring and control. The costs of the new systems may not be lower and the savings may never be realized.

It is recommended that a modular, flexible CEMC system be procured as the first phase of a multi-stage plan for the CU Campus. After the first stage is operating, the market can be evaluated to see if the remainder of the program is justified.

CHAPTER VII

CONCLUSIONS

A. The Future

The cost of CEMC systems is partially related to the declining costs of miniaturized electronic components. As the cost of semiconductor components decreases, the price of the electronic-based equipment will drop. However, the labor and wiring costs, which are a large part of the installation cost, will continue to rise. This will cause the overall cost of CEMC systems to increase.

The distributed processing arrangement is the primary system architecture to be used in the future. This arrangement, which uses microprocessors in remote locations in the interface devices and sensors to perform control and scanning functions independent of the CPU, allows the CPU to perform more calculations and optimize energy use.

A smart sensor is the combination of a sensor with a microprocessor. The microprocessor enables the sensor to recognize its own address and performs the analog to digital conversion at the point. This reduces the chance for errors because the digital signals are less prone to interference and can be checked by the system. The address recognition permits the smart sensor to act as a

junction box. Other sensors can be wired to it in a series circuit arrangement. The need for individual wire runs to the interface device is eliminated. The fewer wire runs will reduce the material and labor costs [28, 30].

New technology is being developed that will allow a person to carry a hand-held terminal that can be plugged into the field panel. The status of the attached sensors can be checked. The necessary changes and adjustments can be made and checked without contacting the central console [30].

The electronic technology improvements will create more powerful hardware for a lower cost. The computer memory will have a greater storage capacity in a smaller module as LSI technology improves. The advances will allow the creation of more capable computers which will control the buildings with less and less input from the operator.

CEMC systems are being considered for the control of solar heating systems. The San Diego Veterans Hospital installed a CEMC system in 1977 to perform the routine scanning and control functions. The installation of solar panels is being considered to heat the facility and the domestic hot water. The system will be programmed to examine the outside conditions and control the mix between the solar and conventional heating systems [3].

The wiring cost for a system installation may range from 30 to 75% of the total job cost. An idea to help reduce the cost is to transmit the control signals over the regular A.C. wires that power the equipment. The concept is being studied and worked on to make it a reality in the future. An alternative is to develop a wireless transmission mode. A third concept is to transmit the signals as light pulses using fiber optics. This scheme would replace the copper cables with less expensive fiber glass cables.

These hardware advances are only a few of the ideas that are being pursued by the industry. They are also working to find ways to improve the existing systems and to use them more effectively.

B. Recommendations

A CEMC system is able to reduce facility energy and labor costs when it is properly applied. The key is to design a system that meets the precise needs of the facility. Over- and under-designed systems only discourage owners from reinvesting in the technology as it improves.

The owner must be actively involved in the system procurement. Some questions that should be asked are:

1. What is the recommended minimum size facility for the system that is being considered?

2. Can my own personnel modify the operating software to expand the number of points connected to the system?

3. Are the applications programs modular? Can new routines be added when necessary?

4. Can additional hardware components such as memory or printers, etc., be added?

5. Is it a distributed processing system in which the intelligent field panels can operate independently from the central control point?

6. Can more than one console be installed to divide the control responsibilities among various departments?

7. What is the approximate annual maintenance cost?

8. How skilled do the maintenance personnel have to be?

9. Does the system need the costly hardware components to do its job, or are they just to have items?

10. Examine the potential savings from each point and compare it to the installed cost.

These questions are not a complete list. The owner and the designer must learn about the system so that an intelligent choice can be made. The result will be a CEMC system that does its job and saves the funds as promised.

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APPENDIX A

INDIVIDUALS AND INSTITUTIONS INTERVIEWED

The companies listed were either contacted by telephone at their Denver area office or sent the sample letter included in this appendix.

Allen Bradley Co.*	Cleveland, OH
Honeywell Corp.	Denver Office
Hughes Micro Electronic Div.*	Newport Beach, CA.
IBM*	Denver Office
Johnson Controls, Inc.	Denver Office
MCC Powers Corp.	Denver Office
McQuay Group/McQuay Perfex, Inc.*	Minneapolis, MN.
Pacific Technology, Inc.*	Renton, Was.
Robertshaw Controls Co.	Denver Office

*Indicated that the firm did not respond or did not wish to participate in this report.

The following typical letter was sent to the manufacturers not located in the Denver metropolitan area.

765 Arapahoe Ave.
Boulder, CO 80303
___ February 1979

ABC Control Co.
123 Any Street
Anywhere, CO 98765

Dear Sir:

I am a Navy Civil Engineer Corps Officer currently studying for my Master's Degree in Civil Engineering at the University of Colorado.

My research report concerns Central Energy Monitoring and Control (CEMC) Systems. Part of my report will deal with the technology and systems available today. I would like to obtain brochures and technical information about the hardware, software, and capabilities of your ________________________ CEMC System. If you will be updating this system or featuring a new system, I would like to use this information in my report so that it will be as up-to-date as possible.

Thank you for your assistance.

Sincerely,

William L. Rudich

The persons listed below were contacted to collect information about the different manufacturer's CEMC systems.

Mr. George Eckert	Johnson Controls, Inc.
Mr. Robert Alpers	MCC Powers Corp.
Mr. Dennis Rooks	Robertshaw Controls Co.
Mr. Thomas Turek	Honeywell Corp.
Mr. Brigham Young	Robertshaw Controls Co.

765 Arapahoe Ave.
Boulder, CO. 80302
___ February 1979

Mr. John Smith
ABC Energy Systems, Inc.
Denver, CO. 80000

Dear Mr. Smith:

As I stated in our telephone conversation of ___ February, I am enclosing my questionnaire. I hope that you will be able to look it over before our meeting on the ___ of February. Your answer will be very valuable for the portion of my report on the present CEMC technology.

I am looking forward to our meeting on ___ February. If there is any question on what I am looking for please contact me at 443-3954. Thank you for your assistance.

Sincerely,

William L. Rudich

The following questions are about Central Energy Monitoring and Control (CEMC) Systems. The answers will be used in a research report chapter on the technology available on today's market. Please think about your answers which I will write down during an interview.

1. What is the estimated cost for the system
    a) Central hardware
    b) Wire runs
    c) Instrumentation

2. Are the costs for CEMC Systems rising or decreasing?

3. How do you develop an initial or conceptual cost estimate?

4. Using well-defined plans and specs how closely can you give the final system cost?

5. Do you have any recommendations about how to specify and procure CEMC Systems on a competitive bid basis?

6. Is there a recommended minimum-size building for your system?

7. What should be designed into new HVAC systems so that they can be connected to a CEMC System in the future?

8. What technical expertise is required to modify the system software?

9. How much time and money does it take to change the system's hardware and software operations?

10. Do you see any new technological breakthroughs that will greatly change and improve the systems?

11. When do you feel that technical improvements to the systems will cease to be economically justified?

12. Can you interface your system with those of other manufacturers? Is your software modular or is it written for a specific application?

13. Does your system rely on distributed processing? Do you currently feature or plan to feature "smart sensors?

14. Could you give the approximate annual maintenance costs for your system's central hardware, wire runs and instrumentation?

The following facilities were listed by the manufacturers as having CEMC Systems installed and operating. They were sent questionnaires to determine their opinions about their systems.

Institution	System Manufacturer
Auburn University, Auburn, AL*	Robertshaw
Blue Cross/Blue Shield, Denver, CO.	MCC Powers
Illinois Bell, Chicago, IL.*	Johnson Control
Indiana University,*Bloomington, IN.	Johnson Control
International Monetary Fund,** Washington, D.C.	Robertshaw
MGM Grand Hotel, Reno, NE.*	Johnson Control
Mountain Bell, Denver, CO.	Honeywell
Northwest Bell, Seattle, WA.*	Robertshaw
San Joacquin County, Stockton, CA.	Honeywell
Skyline High School, Longmont, CO.	MCC Powers
St. Lawrence University, Canton, N.Y.	Honeywell
U.S. Marine Corps Base Camp Pendleton, CA.	Honeywell
U.S. Naval Academy, Annapolis MD.	Johnson Control
U.S. Naval Hospital, Long Beach, CA.	Johnson Control
U.S. Postal Service Annex, Denver, CO.	MCC Powers
U.S. Postal Service General* Mail Facility, Colorado Springs, CO.	MCC Powers

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*Indicates that the questionnaire was not returned.

**Indicates that a questionnaire was not sent, but that the the information was taken from an article written by a non-company source.

Institution	System Manufacturer
University of Minnesota, Minneapolis, MN.	Honeywell
University of South Dakota Vermillion, SD.	Johnson Control

765 Arapahoe Ave.
Boulder, CO. 80302
___ February 1979

Facilities Director
A Company
Anywhere, USA 12345

Dear Sir:

I am a graduate student at the University of Colorado. My Master's research report concerns automated Central Energy Monitoring and Control (CEMC) Systems. The manufacturer of the system installed in your facility has cited you as a successful application of this technology.

Part of my report will compare the customer's satisfaction with the system against the manufacturer's claims. I have developed the attached questionnaire to learn what present users like and dislike about CEMC Systems. I would be very grateful if you would answer the questions and add any appropriate comments and promptly return it in the envelope provided.

You help with this survey will be very valuable to my research report. Thank you for your assistance.

Sincerely,

William L. Rudich

The following questions are designed to find out how you feel your Central Energy Monitoring and Control (CEMC) System is performing. Please circle the choice that best represents your opinion. If you must circle more than one choice to give your feelings, please do so. If none of the choices are appropriate please make a written comment in the space provided or at the bottom of the last page.

1. Facility name: ______________________________

2. Date CEMC System was installed: _______________

3. Number of buildings connected to the system: _______

4. Approximate number of square feet served by the system: ___________________________

5. Which manufacturer's system do you have?
   a) Honeywell Delta 1000
   b) Honeywell Delta Distributed Control System
   c) Robertshaw DMS 2400-3
   d) IBM System-7/Series 1
   e) Johnson Control JC/80/__
   f) MCC Powers S170
   g) Other ____

6. How did the actual savings for labor and energy compare with those forecast prior to installation?
   a) Much greater than predicted
   b) Slightly greater than predicted
   c) About equal to the prediction
   d) Less than predicted
   e) Much less than predicted

7. How long do you feel it took for the system to pay for itself?
   a) Less than 1 year
   b) 1 to 3 years
   c) 3 to 5 years
   d) Over 5 years

8. How long did it take to "debug and fine tune" the system so that it ran to your satisfaction?
   a) Less than 3 months
   b) 3 to 6 months
   c) 6 months to 1 year
   d) Over 1 year
   e) The system never has and never will run to my satisfaction

9. What types of problems have you encountered with the system?
   a) False signals indicating an occurrence that did not happen such as showing the temperature too high when it was within normal limits.
   b) Printer malfunctions
   c) System fails to perform as intended
   d) Other (Please specify)

10. What caused the problems described in Question 9?
    a) Sensors not located properly
    b) Operator errors
    c) System software not properly programmed
    d) Improper maintenance of system components
    e) System is not adequate for facility needs
    f) Other (Please specify)

11. A. Have you tried to expand your system?
    a) Yes b) No

    B. Did you encounter problems during the expansion phase?
    a) No, was able to reprogram the system and add points with own personnel
    b) Needed to purchase new system hardware
    c) Needed to bring in an outside programmer to modify the software
    d) System could not be expanded
    e) Other (Please specify)

    C. Did you have to go to the manufacturer to accomplish the expansion?
    a) Yes b) No

    D. For government users only: Did you have problems justifying "sole source" procurement instead of bids?
    a) Yes b) No

12. Do you?
    a) Contract the system maintenance
    b) Have a system that is simple enough that your own personnel can perform routine maintenance and repairs

13. Are parts readily available?
a) Yes b) No

14. Is system maintenance a problem?
a) Yes b) No

15. Please give (if possible) the estimated cost of the annual maintenance: ____________________

16. A. Do you consider the system reliable?
a) Yes b) No

B. After the break-in period how often did the system malfunction or break down?
a) Once a month or more
b) Once in 3 months
c) Once in 6 months
d) Once a year or less

17. How do your operating and maintenance personnel accept the system?
a) Depend on it and have a lot of faith in it
b) Will trust it in routine but not critical situations
c) Have no faith in its capabilities and would like to see it removed
d) Other (Please specify)

18. A. What equipment had to be added to your facility so that the system would work when installed?
a) Control circuits and devices
b) New valves
c) New sensors
d) Other (Please specify)

B. If possible please give the cost that these items added to that of the system: __________

19. Do you feel that the system was oversold, meaning that it does not do as much as promised prior to installation?
a) Yes b) No

20. How many people are required to effectively operate and keep the system running during a shift?
a) 1
b) 1 to 3
c) 3 to 5
d) Over 5

21. Would you recommend investing in a CEMC System for a facility similar to your own?
    a) Yes b) No

22. Has the manufacturer helped you to utilize your system more effectively after the break-in period?
    a) Yes b) No

23. Additional comments (Please include comments concerning what you would do differently if you were to procure another system after your experience with your present one).

APPENDIX B

CENTRAL ENERGY MONITORING AND CONTROL SYSTEM TERMINOLOGY

TERMINOLOGY

1. Architecture: The components of a CEMC system and how they are connected [13].

2. Asynchronous System: A system where the speed of a system operation is governed by start/stop pulses generated by the CPU [13].

3. Offline Programming: A process where the program for the controlling computer is translated into machine language (compiled) on a different machine prior to reading it into the control computer's memory [12].

4. Optimization: The minimization of energy use by the application of central control techniques [10].

5. Synchronous System: A system where the speed of operation is governed by a single control signal. This system saves memory space, but it is not able to easily interface operations between slow and high speed components such as a printer and the CPU [13].

The following definitions are reproduced from the Swanson-Rink University of Colorado Master Plan for a Centralized Monitoring and Control System produced in December 1973 [31].

1. Analog: Pertaining to representation by means of continuously variable physical quantities. (Contrast with digital)

2. Analog-to-Digital Conversion: The process of converting a continuously varying quantity such as temperature, voltage, or frequency to a finite number suitable for direct processing by a digital computer or processor.

3. Binary Digit: Either of the characters, 0 or 1, representing one of two possible states. (Often referred to as a Bit.)

4. Cathode Ray Tube (CRT): A special-purpose electron tube often used for displaying data visually on a fluorescent screen by deflecting electron beams controlled by voltage or current.

5. Central Processing Unit (CPU): That part of a computer which includes the circuits controlling the interpretation and execution of instructions.

6. Closed Loop Control: An automatic control technique through which feedback is used to link a controlled process back to the original command signal. The feedback mechanism compares the actual controlled value with the desired value, and if there is any difference, an error signal is created that helps correct the variation. In automation, feedback is said to "close the loop."

7. Coaxial Cable: Cable that consists of a tubular conductor surrounding a central conductor held in place by insulating material. Used for transmitting high frequency signals.

8. Computer: A data processor that can perform substantial computation, including numerous arithmetic or logic operations, without human or operator intervention.

9. Computer Program: A series of instructions, statements, plan or procedure in a form or "language" acceptable to a computer, prepared in order to achieve a specific result or solve a specific problem. See "Software."

10. Digital: Data in the form of discrete digits representing a finite quantity. (Contrast with Analog.)

11. Digital Computer: A computer in which discrete representation of data is mainly used. A computer that operates on discrete data by performing arithmetic and logic processes on these data.

12. Hardware: Physical equipment, as opposed to the computer program or method of use, e.g., mechanical, magnetic, electrical or electronic devices. (Contrast with Software.)

13. Memory: Denotes data retention inside the computer (core storage) or outside of the computer (disc storage). In either case, the term means collecting and holding pertinent information needed by the computer.

14. Modem: Derived from Modulator/Demodulator. An interface unit to create a change in a data signal to adapt to a change in signal transmission conductors or media (such as to transmit data received from a coaxial cable system for transmission on ordinary voice-grade telephone pairs, and vice-versa).

15. Multiplex: (1) To execute several functions simultaneously in an independent but related manner. (2) To interleave or simultaneously transmit two or more messages on a single channel.

16. Operator's Console: An input/output device, including voice intercom, used to communicate with the control system and Central System.

17. Scan: To examine sequentially, part by part or point by point.

18. Serial Transmission: In telecommunications, transmission at successive intervals of signal elements constituting the same date signal. The sequential elements may be transmitted with or without interruption, provided that they are not transmitted simultaneously.

19. Software: A set of computer programs, procedures, and associated documentation concerned with the operation of a computer, e.g., compilers, library routines, manuals, flow charts. (Contrast with Hardware.)

20. Three mode switching: Three state switching operations such as fast-slow-stop, summer-winter-auto, day-night-auto, etc.

21. Two mode switching: Two state switching operations such as start-stop, on-off, open-close, etc.

APPENDIX C

THE TRI-SERVICE GOVERNMENT SPECIFICATION

The intent of this specification is to provide a CEMC system with a distributed control architecture. The control capability is spread among several locations instead of being concentrated at one point. The specification is not complete, and will be revised after some experience with its use is gained. Problems such as the responsibility for maintaining existing controls, the reliability, and which functions will be contained in the field panels must be addressed.

The specification is divided into six sections. The first covers the general requirements for the CEMC system and its installation. An overview of the system hardware and how it is expected to function is described. The scope of the installation including the buildings to be connected, the operator training, the quality standards for the materials, and the debugging and testing procedures are written in detail. The specification prohibits the use of products from sources not regularly engaged in the production of CEMC components. The installation of these products is in accordance with the manufacturer's instructions.

The specification permits the use of existing building controls that are compatible with the CEMC system. The original design of the devices cannot be altered by internal or external devices. The contractor

is required to test and inspect all of the control devices to be used with the CEMC system. A test report must be submitted to the government. Any malfunctioning controls will be repaired by the government. After the repairs are made the control equipment becomes the contractor's responsibility until the system is accepted by the government.

The section contains a list of definitions for CEMC terminology and abbreviations. It is included to preclude a misunderstanding about the intent of a term in the specification. To help with the understanding of the system, all of the hardware components installed must be labeled.

The general requirements furnish the information about the construction contract. The time for completion, the submittals required, test results, and the quantity of operating literature to be given to the client are spelled out. The successful bidder is required to conduct two design meetings with the government to insure that all of the contract provisions will be met by the system to be installed.

The specification contains materials which are to be used as a check list to prevent the accidental deletion of a point. The functions and operations are described in clear language for an easy understanding of the capabilities required.

The second portion of the specification is concerned with the materials for the field devices. The standards for the remote equipment such as sensors, field panels, multiplexer panels, function cards, etc., are given. The wiring, capabilities, and installation of these devices along with a detailed written description of the intended function within the system is detailed. The information required from the manufacturer to be submitted along with the shop drawings is listed. In this section and all of the others that follow it, any clarifications must be looked up in the first section.

The third section deals with the equipment contained in the central control area. Any required environmental conditions in the space are stated. The computer, communications controller, auxiliary power supply, memory and input/output devices are covered in this section. The required features for each component are described in detail. The different specialty keys on the operator's keyboard are listed. The required size of the auxiliary disc memory is given. This section is included to give details on the central equipment. It is very important to coordinate the requirements with the general requirements section.

The fourth section describes the software specifications. The section can be used for a FORTRAN or BASIC language system. The executive program is a real-time

operating system. Debugging and diagnostic programs are provided.

The specification lists the minimum software features that should be included in the operating system. It includes a multi-tasking, foreground/background, multi-user system. The multi-user portion allows several input/output devices to issue commands to the system. The foreground/background feature enables the new programs to be developed without disrupting the operations of the existing routines. Multi-tasking means that more than one program can be issuing commands to the system at the same time.

The minimum command software features are listed. They may be expanded by the manufacturer to support additional application program routines. A set of performance criteria is set down for the software modules. It requires the Command line Mnemonic Interpreter (CLMI) to contain full English language words so that the operators do not need to be familiar with computer language to effectively use the system. Examples of error messages for improper input commands are given. The command software also contains the parameter definition process, the report generator, index, graphics, alarm and console software routines. They are defined and given the minimum acceptable features.

The application program specification contains a list of routines that permit automated control independent of the operator over the facility systems. The intent is to establish a performance standard for the routines. They are required to be written in FORTRAN. The nineteen listed functions are defined as to what they are supposed to do. The data that is to be obtained and available to the operator is listed.

The software for the Central Communication Controller (CCC) and field panels is used to control the transmission of data between the CCC and the remote field panels. Alarm reporting, manual operations, power demand recording, and weather information dissemination are included in the routines for the CCC. The field panels' ability to stand alone if the link to the central control units is severed is based on its software. The necessary functions to ensure this mode of operation are included in this part of the specification.

The contractor must create an ideal building with climate, equipment, and utility data to demonstrate that the software routines will perform satisfactorily. The process control situations are listed. The reaction of the systems to changes in the inside and outside environment must be shown to be within specified guidelines. The contractor must also show the system's

ability to optimize the use of energy in this test situation.

The data transmission links are covered in the fifth section of the specification. All of the signals must be digital. The error rate for the communication system is not given as an actual number. It is given in terms of the number of detected errors and the statistical ratio of the detected to undetected errors. The physical characteristics of the various transmission modes such as twisted wire pairs, coaxial cable, telephone lines and radio transmissions are given. The installation requirements for splices, grounding, etc., are listed.

The last part of the Tri-Service specification deals with system maintenance. It can be used as part of the initial procurement contract or for a separate maintenance service contract. Periodic minor and major inspections and emergency repair service are included. The entire system including the central equipment, sensors, transmission lines, and peripheral equipment is covered by the contract.

The contractor can recommend system modifications. It is the contractor's responsibility to implement software maintenance updates.

The Tri-Service specification is designed to be used as guide when writing specifications. It must be

tailored to the individual job so that it provides as much specific information as possible.

The Industry's View

Some of the manufacturers interviewed were familiar with the Tri-Service specification. They were not pleased with the document. Some of them felt that the concept of writing a specification that would be open to all systems is not practical due to the variation in features and capabilities. The intent of the specification is to obtain standard systems from the manufacturers. One company complained that its standard software packages could not be used without extensive modifications. Another has to create a new system that is quite different from its standard product. The same representative believes that the system obtained is too complex for regular commercial use. He stated that the software will require a programmer to modify the software. He did believe that each revision of the specification was improving, and that it might eventually meet its goal.

Thesis
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